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SUBTASK MEMORANDUM

Task: 3.3 How Well Do Measurements Characterize Critical Meteorological Features

Subtask: 3 Measurements of Gustiness

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Date: August 24, 2004

A number of stations reporting meteorological data during CRPAQS included wind gust (or peak wind) as one of their measurables. This task investigates the usefulness of wind gust data in relation to the understanding of the origin of suspended particulate matter within the CRPAQS study area. Since gustiness is a short-term phenomenon, continuous particulate measurements are of particular interest. In addition, because gustiness is highly localized, the sites examined were required to have particulate measurements and meteorological measurements collocated. Lastly, wind-borne dust is associated principally with dry soil conditions.

The CRPAQS central monitoring site at Angiola provided the best source of such data. This site had collocated b_{sp}, $PM_{10,}$ and $PM_{2.5}$ measurements and represented the agricultural areas that comprise a large portion of the CRPAQS study area where fugitive dust could be an issue. Wind-gust data was also recorded at Angiola, though meteorological data were missing for September through November 2000, a period characterized by typically dry conditions.

Table 1 presents the frequency of occurrence distribution of hourly-averaged coarse particulate mass as a function of wind speed. For the purposes of this discussion, wind speed refers to scalar wind speed and coarse mass is defined as the difference between the PM_{10} and $PM_{2.5}$ mass. Data during rainy periods and the 48 hours after such periods were removed in a very simple attempt to limit the analysis to periods when the surface was dry or close to dry. Also included in the table are average concentrations within the wind speed bins and the frequency that concentrations were greater than or equal to 100 µg/m^3. Finally, similar frequency distributions are presented for $PM_{2.5}$ (“fine”) concentrations for comparison.

The Angiola statistics in Table 1 suggested a relationship between wind gust and wind speed hourly average. There is a notable increase in higher coarse mass concentrations when the average wind speed in greater than 8 m/s, and a similar increase when gusts greater than 9 m/s are noted. The two apparent thresholds for wind-borne dust generation may be an indication that the average data and the gust data provide essentially the same information, with peak gust speeds inherently higher than average wind speeds for any given hour. **Figure 1** presents a comparison of average and peak wind speeds for the dataset. The plot shows that, on average, wind gusts are about 28% higher than the average wind speed. For example, wind gusts of 10 m/s would be expected to be associated with 8 m/s average wind speeds, which agree with the two thresholds for wind-borne dust noted above.

In reviewing Table 1, there is some evidence that peak wind data may provide additional information regarding wind-borne dust that average wind speed data do not provide. Looking closer at the frequency of occurrence of high concentrations (greater than or equal to

100 µg/m^3) for each of the two thresholds (shaded areas), sixteen events are noted when average wind speeds are greater than 8 m/s, whereas 25 events are noted when gusts are greater than 9 m/s. This leads to the possibility that the 8 m/s threshold for average wind speed may not sufficiently account for increases in concentrations. Closer review of Table 1 shows a second, much weaker jump in concentrations for average wind speeds greater than 6 m/s. Returning to Figure 1, an average wind speed of 6 m/s is very close to where gusts of 9 m/s begin to occur. Thus, the more minor jump at 6 m/s is likely due to higher gusts that begin to occur at this average wind speed. Indeed, if the average wind speed criterion is lowered to 6 m/s, 26 high coarse PM concentrations are noted, essentially identical to that for the gust data.

The three other CRPAQS sites that had continuous PM data collocated with wind measurements did not record peak wind gust (Bakersfield, Fresno, and Corcoran). . Nevertheless, the relationship between coarse concentration and wind speed noted above confirm the wind threshold for fugitive dust established for Angiola. The data from these sites are shown in **Tables 2, 3, and 4.** Specifically, rapid increases in coarse concentration are noted at between 7 and 8 m/s, with a second, less prominent increase evident about 2 m/s below this threshold. For the Fresno site, the effect is barely noticeable, since average wind speeds do not get above 6 m/s.

To further investigate potential effects of high winds and gusts, wind data from Altamont Pass were reviewed. While this site did not collected continuous PM_{10} data, the site had collocated wind and b_{sp} measurements. Though b_{sp} is more correlated with $PM_{2.5}$ rather than with coarser fractions of PM that are more closely associated with mechanical processes, it provides the only potential alternative. In addition, both wind speed and b_{sp} data were readily available as 5-minute averages, with 5-minute peak gusts. A summary of b_{sp} as a function of wind speed is presented in **Table 5**.

Looking at results that include November and December, b_{sp} values are highest at low wind speeds and decrease as wind speeds increase, consistent with wintertime $PM_{2.5}$ events that occur under stable, low wind speed conditions. As expected, the trend is consistent with the $PM_{2.5}$ (“fine”) trends noted in Tables 1 through 4. However, the trend noticeably reverses when wind gusts reach approximately 10 m/s. Looking at the September data that is free of the winter PM episodes, b_{sp} readings are essentially independent of wind speeds, with the notable exception that again readings start increasing when wind gusts reach about 9 or 10 m/s. The same pattern is seen if b_{sp} is compared against scalar wind speed rather than peak wind, though the location of the “jump” occurs about 2 m/s lower than the gust results, consistent with the results from Angiola.

Whiles the Altamont Pass results seemed to indicate that wind gust of 10 m/s or greater may be contributing to the coarse PM load, a review of the Altamont Pass wind data showed that the vast majority of the high wind speeds occurred when the winds were out of the west. This allowed for the possibility that the increase in b_{sp} readings could be source related. To investigate this, the Altamont Pass September data set was filtered for winds coming predominantly out of the west (200 - 300°). Table 5 results show that the “jump” at gusts of 10 m/s persists, with values essentially unchanged from the comparison using all data. Again present is the 2 m/s drop in the threshold if average scalar wind speed is used instead of peak wind speed.

In addition to the above site-specific investigation into gustiness, a more general survey of peak wind gust was conducted using the 10-meter wind data collected by NOAA for CRPAQS. This dataset represented a consistently operated, quality assured source of gust data, with a 19-site network that evenly represented all of the meteorological domains within the CRPAQS study area. Review of the NOAA data therefore provides a good opportunity to identify difference in the gustiness of the wind that could be significant. Frequency distributions were created for both average scalar wind speed and peak wind speed for each site, for four meteorologically defined seasons. Data were compiled from the entire CRPAQS study period (November 1999 through February 2001). Plots of these frequency distributions are presented in **Figures 2 through 20.** Note that several sites had missing data during some seasons.

Review of the plots immediately shows the similarity in wind and gust profiles between sites of similar domain characteristics. The following categories emerge:

- Coastal passes. Characteristics include a relatively low frequency of low average and peak winds, with a peak in the frequencies around 5 m/s. In general, there are higher winds in the spring and summer, though winds are always higher than those for other sites reviewed. Peak distribution is significantly shifted in the positive direction. This profile includes Altamont Pass, Pacheco Pass, and Richmond.

- Central Valley sites, including low, eastern foothills. This is the largest category, consisting of over half of the sites reviewed. Characteristics include a high frequency of low average wind speeds, though the frequency of low peak wind speeds is often much lower than that of low average winds speeds. In general, there is a less pronounced shift in the peak wind speed profile that there is for the coastal passes. This profile includes Auburn, Bakersfield, Chico, Chowchilla, Fresno, New Melones Dam, Redding, and Trimmer. The profile for Gaviota is also similar.

- Frequency distributions with peaks at about 4 m/s. Four sites have winds that have neither the consistently high distribution of low wind speed like the valley sites nor the high wind speed from the coastal passes. In addition, there is frequently little difference between the average and peak wind speed distributions, indicating less pronounced gusts. These sites include Arbuckle, Kings River Powerhouse, Lost Hills, Pleasant Grove, and Tejon Pass. All of these sites have the potential for influence by nearby topography.

- Mojave. The Mojave profile is unique, most likely due to its unique, high desert relative to the other CRPAQS sites. This site has the highest winds and the biggest differences between the peak and average wind speed distributions.

- Waterford. The profile for Waterford does not really match any of those for the other categories. The most distinctive feature is that the peak wind speed profile is significantly shifted upward, indicating a more gusty site.

It can be concluded that gustiness plays a relatively small role in generating fugitive soil in the CRPAQS domain. The majority of the sites are characterized by low wind speeds during the dry seasons. Even sites with wind speeds more frequently in the 4 m/s or above range show a relatively small difference between average and peak wind speeds. Of the sites reviewed, only the coastal pass sites, Mojave, and Waterford have profiles that demonstrate gusty conditions. In addition to these generalizations, the following, more specific observations are made regarding the frequency distribution plots:

- Several of the central valley and eastern foothill sites demonstrate more noticeable gusty conditions during the spring and summer months (March through September). This includes Auburn, Fresno, and to some degree New Melones Lake, Redding, and Trimmer. It should be noted that his is directly opposed to the high PM periods of interest for CRPAQS (the fall and winter), again downplaying the role of gustiness for CRPAQS.

- The Auburn site has a unique "jag" in the peak wind speed frequency distribution that persists through both the spring and summer periods. Its uniqueness implies the possibility that gustiness is a function of something other than wind speed, such as direction.

In conclusion, there is evidence that winds at speeds of approximately 8 m/s or greater can contribute to coarse particle concentrations. Typically, gusts of around 10 m/s are common at this speed, and it is unclear as to how much additional information peak wind speed data provides beyond average wind speed data. However, there are indications that higher gusts associated with lower wind speeds (e.g. 10 m/s gusts when average wind speeds are closer to 6 m/s) may provide explanations for higher coarse mass concentrations.

High wind speeds and gusts are likely to be rare in most of the CRPAQS study area, and the data available for determining the relationship between coarse mass concentrations and wind gusts is limited. Continuous b_{sp} measurements were much more common in the CRPAQS study area, and while these measurements are more closely associated with $PM_{2.5}$, there appears to be a contribution associated with high wind speeds and gusts.

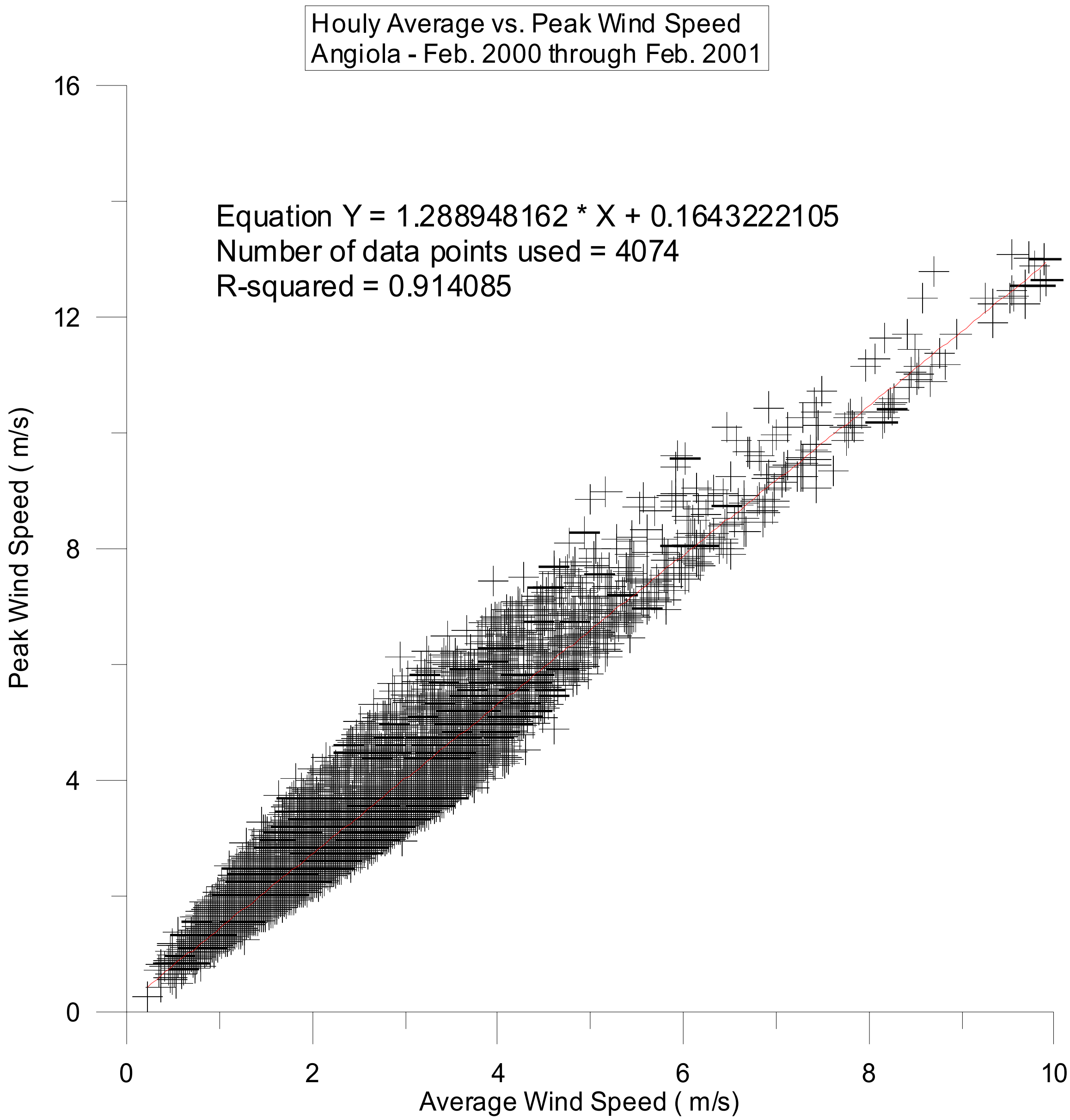

Figure 1. Comparison of Hourly Average Wind Speed and Peak Wind Speed

Table 1. Angiola Hourly Particulate Mass / Wind Speed Frequency Distributions

Coarse Mass	Average Hourly Wind Speed (m/s)										
ug/m^3	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	Total
0 - 49	166	700	840	628	268	75	44	15	8	2	2746
50 - 99	27	120	196	191	61	27	13	11	3	4	653
100 - 149	5	14	23	30	4	2	5	3	3	3	92
150 - 199	1	2	6	4	2	2			5		22
200 - 249	1	1	1	2			1			1	7
250 - 299	2	1		2						1	6
300 - 349	1			1					1		3
350 - 399			1				1		1	1	4
800 - 849	1										1
Total	204	838	1067	858	335	106	64	29	21	12	3534
% > 100 ug/m^3	5.4%	2.1%	2.9%	4.5%	1.8%	3.8%	10.9%	10.3%	47.6%	50.0%	3.8%
Avg. Conc. (ug/m^3)	39.2	29.6	35.2	40.2	35.7	39.0	49.1	49.5	114.2	128.8	36.6

Coarse Mass	Hourly Wind Speed Gust (m/s)														
ug/m^3	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	Total
0 - 49	28	383	672	676	416	259	170	69	43	14	9	4	1	2	2746
50 - 99	6	65	121	183	121	60	35	24	13	11	7	4	3		653
100 - 149	1	8	17	25	16	8		3	1	6	2	2	3		92
150 - 199	1		4	5	2	2	1	2			3	2			22
200 - 249	1	1	1	1		1				1			1		7
250 - 299	1	1	1	1	1								1		6
300 - 349	1				1							1			3
350 - 399			1							1			1	1	4
800 - 849	1														1
Total	40	458	817	891	557	330	206	98	57	33	21	13	10	3	3534
% > 100 ug/m^3	15.0%	2.2%	2.9%	3.6%	3.6%	3.3%	0.5%	5.1%	1.8%	24.2%	23.8%	38.5%	60.0%	33.3%	3.8%
Avg. Conc. (ug/m^3)	74.4	29.0	32.2	37.3	37.9	37.4	34.0	41.7	35.7	70.4	70.5	103.9	147.2	139.0	36.6

Fine Mass	Average Hourly Wind Speed (m/s)										
ug/m^3	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	Total
0 - 49	163	712	1005	839	332	103	64	29	21	12	3280
50 - 99	33	100	48	14	2	3					200
100 - 149	8	23	14	4	1						50
150 - 199		3		1							4
Total	204	838	1067	858	335	106	64	29	21	12	3534

Fine Mass	Hourly Wind Speed Gust (m/s)														
ug/m^3	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	9 - 10	10 - 11	11 - 12	12 - 13	13 - 14	Total
0 - 49	33	372	711	845	553	329	204	96	57	33	21	13	10	3	3280
50 - 99	7	65	86	34	3	1	2	2							200
100 - 149		20	18	11	1										50
150 - 199		1	2	1											4
Total	40	458	817	891	557	330	206	98	57	33	21	13	10	3	3534

Table 2. Bakersfield Hourly Particulate Mass / Wind Speed Frequency Distributions

Coarse Mass	Hourly Average Wind Speed (m/s)									
ug/m^3	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	Total
0 - 49	944	1736	881	269	26	1	1			3858
50 - 99	453	647	188	49	18	5	1			1361
100 - 149	26	32	1	2	3	1				65
150 - 199			1		3					4
200 - 249		1	1	2	1	1	1	2	1	10
250 - 299			1	1		1				3
350 - 399						1				1
550 - 559								1		1
600 - 650				1						1
Total	1423	2416	1073	324	51	10	3	3	1	5304
% > 100 ug/m^3	1.8%	1.4%	0.4%	1.9%	13.7%	40.0%	33.3%	100.0%	100.0%	1.6%
Avg. Conc. (ug/m^3)	42.5	40.4	36.2	39.9	63.4	139.9	96.3	331.3	236.0	40.7

Fine Mass	Hourly Average Wind Speed (m/s)									
ug/m^3	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	Total
0 - 49	1034	2060	1035	321	51	10	3	3	1	4518
50 - 99	262	252	27							541
100 - 149	104	89	10	3						206
150 - 199	23	14	1							38
350 - 399		1								1
Total	1423	2416	1073	324	51	10	3	3	1	5304

Table 3. Fresno Hourly Particulate Mass / Wind Speed Frequency Distributions

Coarse Mass	` Hourly Average Wind Speed (m/s)						
ug/m^3	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	Total
0 - 49	794	1506	886	465	129	7	3787
50 - 99	25	105	70	18	9	3	230
100 - 149		4	2	2	1	1	10
150 - 199			1				1
200 - 249						1	1
Total	819	1615	959	485	139	12	4029
% > 100 ug/m^3	0.0%	0.2%	0.3%	0.4%	0.7%	16.7%	0.3%
Avg. Conc. (ug/m^3)	14.4	20.1	24.2	21.3	27.0	58.5	20.4

Fine Mass	Hourly Average Wind Speed (m/s)						
ug/m^3	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	Total
0 - 49	385	1057	891	479	136	11	2959
50 - 99	253	355	58	5	3	1	675
100 - 149	121	138	10	1			270
150 - 199	60	65					125
Total	819	1615	959	485	139	12	4029

Table 4. Corcoran Hourly Particulate Mass / Wind Speed Frequency Distributions

Coarse	Average Hourly Wind Speed (m/s)									
ug/m^3	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	Total
0 - 49	46	127	77	34	31	1	1			317
50 - 99	24	59	27	28	8	3			2	151
100 - 149	3	4				1		2	3	13
150 - 199		1								1
Total	73	191	104	62	39	5	1	2	5	482
% > 100 ug/m^3	4.1%	2.6%	0.0%	0.0%	0.0%	20.0%	0.0%	100.0%	60.0%	2.9%
Avg. Conc. (ug/m^3)	46.6	42.6	37.3	47.1	37.2	69.4	20.0	130.5	103.4	43.7

Fine	Average Hourly Wind Speed (m/s)									
ug/m^3	0 - 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 6	6 - 7	7 - 8	8 - 9	Total
0 - 49	64	164	98	60	38	4	1	2	5	436
50 - 99	9	27	6	2	1	1				46
Total	73	191	104	62	39	5	1	2	5	482

Table 5. Average 5-minute b_{sp} as a function of Wind Speed

	Oct - Dec 2000	Sep 2000		Sep 2000 (WD from WSW)	
	vs. Peak WS	vs. Peak WS	vs. Avg WS	vs. Peak WS	vs. Avg WS
WS (m/s)	bsp (5-min) mm^{-1}	bsp (5-min) mm^{-1}	bsp (5-min) mm^{-1}	bsp (5-min) mm^{-1}	bsp (5-min) mm^{-1}
0 - 1	67.2	20.9	21.8	21.5	21.6
1 - 2	63.6	24.3	24.8	24.1	26.4
2 - 3	74.7	24	23	24.7	23.9
3 - 4	81.5	23.5	21.5	23.8	22.1
4 - 5	70	23.1	22.5	23.8	24.6
5 - 6	61.5	22.8	26.3	24.8	27.8
6 - 7	50	24.8	26.9	27.4	27.3
7 - 8	49.4	26.4	25.2	27.8	25
8 - 9	45.2	25.3	29.9	26.4	29.4
9 - 10	39.7	26.6	37.3	26.3	37.4
10 - 11	55.5	30.2	46.6	30.1	46.8
11 - 12	52.4	37.3	41.4	37.5	41.6
12 - 13	35.1	43.4	38	43.5	38
13 - 14	23.6	42.1	33.5	42.1	33.5
14 - 15		34.3	51.6	34.3	55.5
15 - 16		33.4		31.9	
> 16		37.3		37.3	

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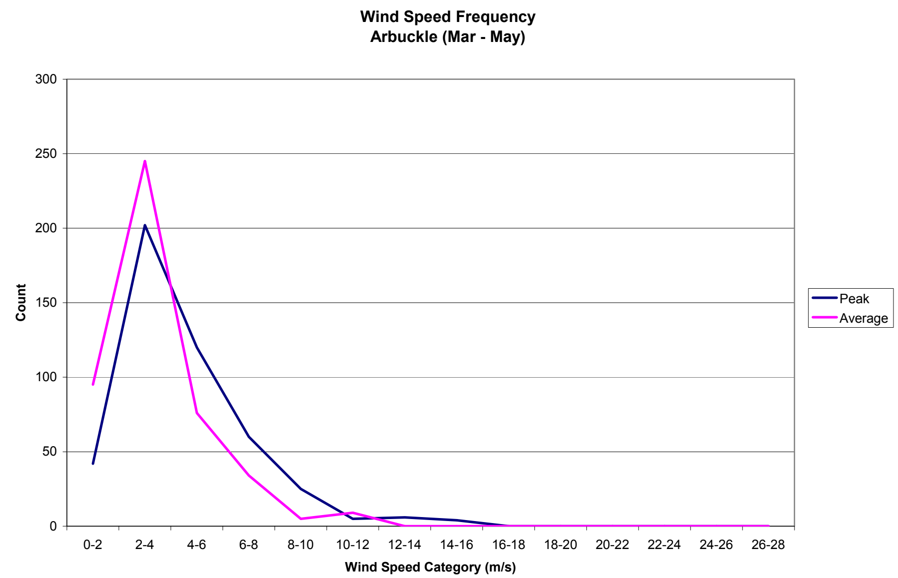
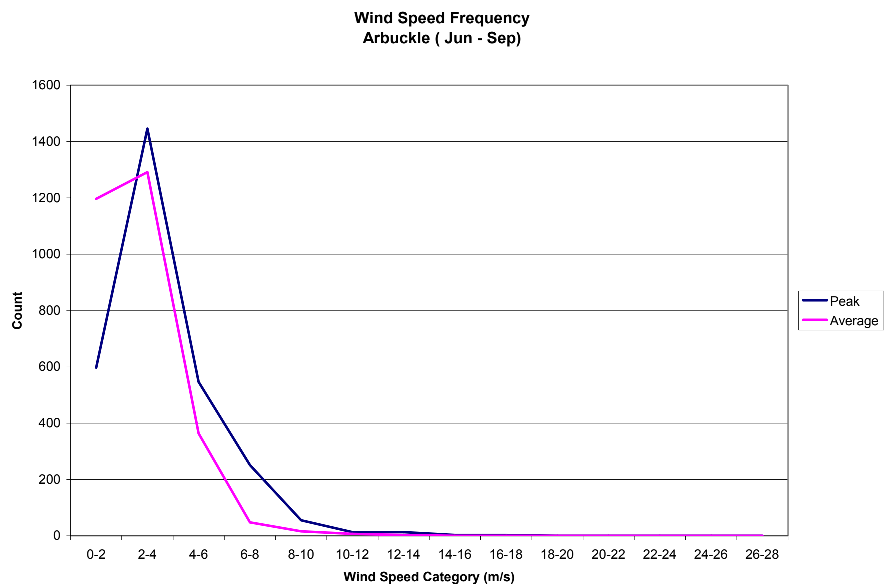




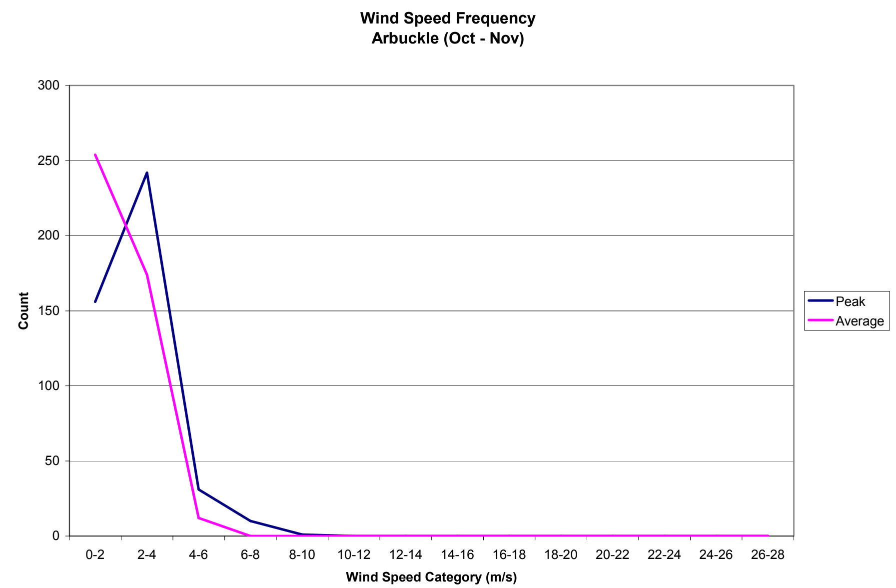
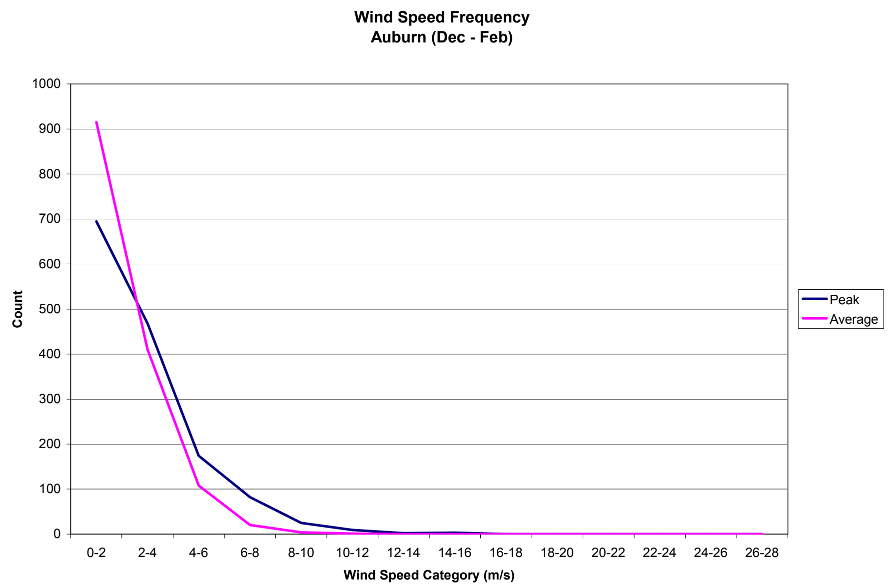
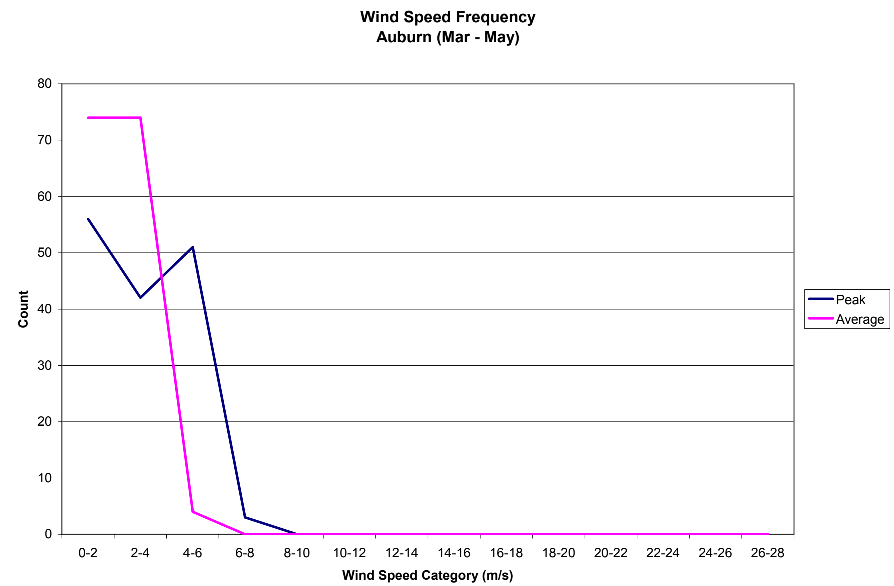
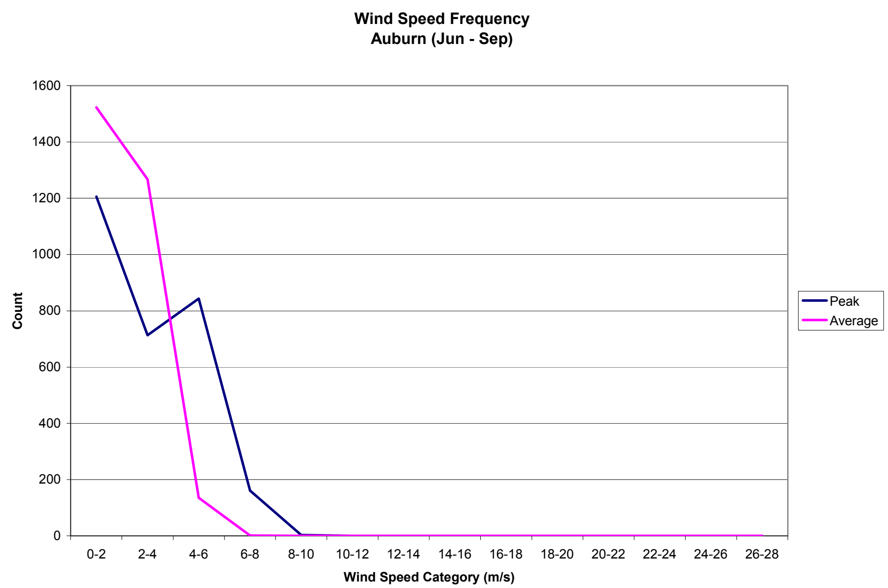


Figure 2. Arbuckle Wind Speed Distributions







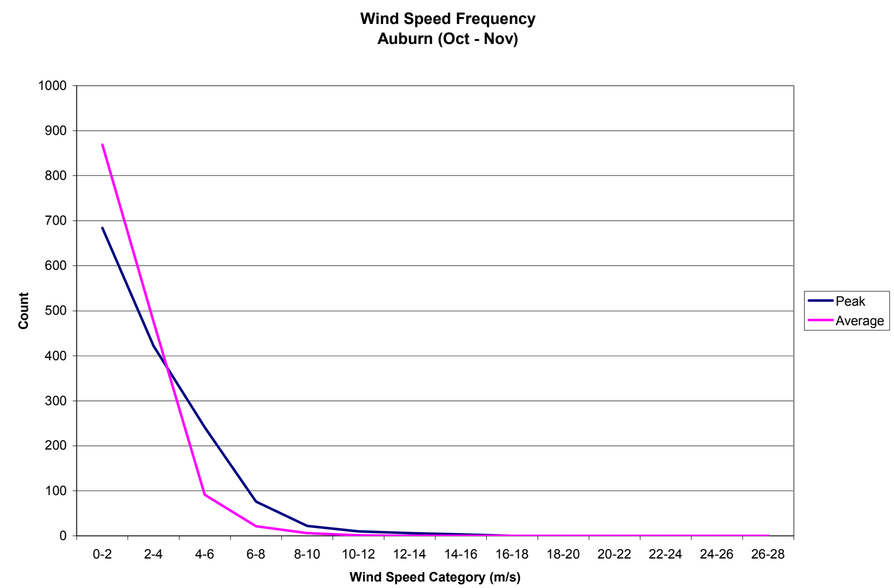
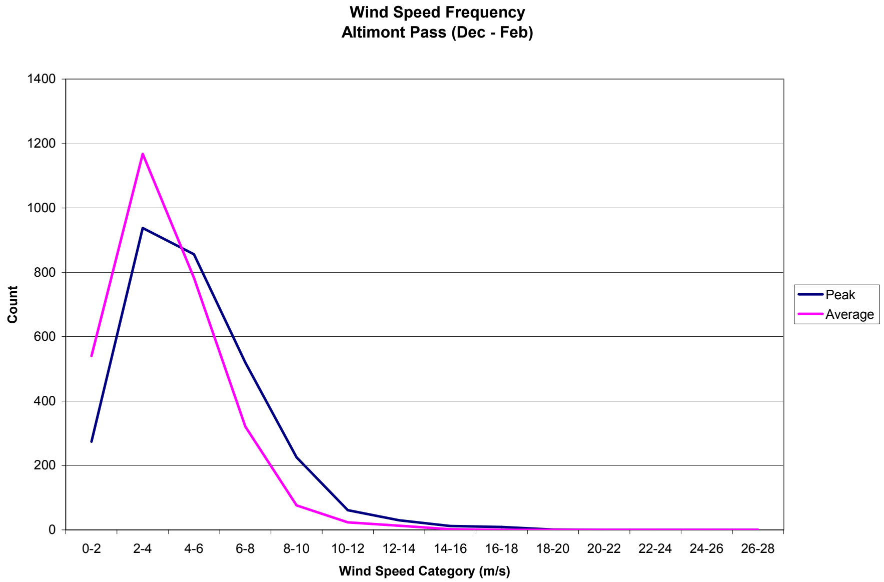
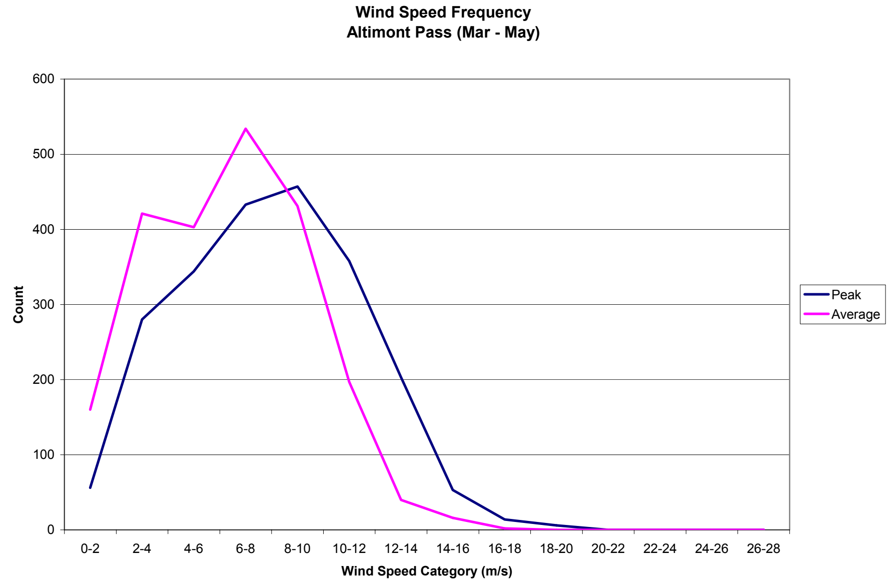
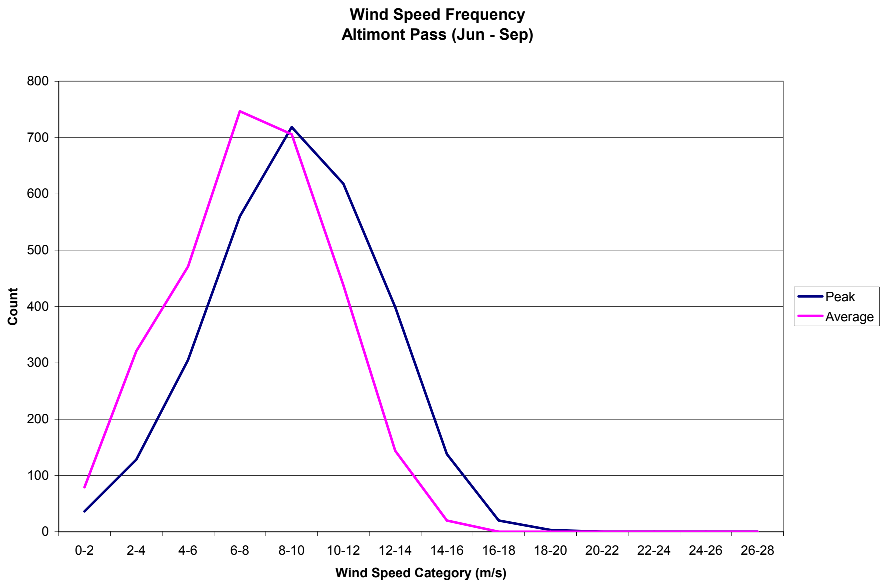


Figure 3. Auburn Wind Speed Distributions







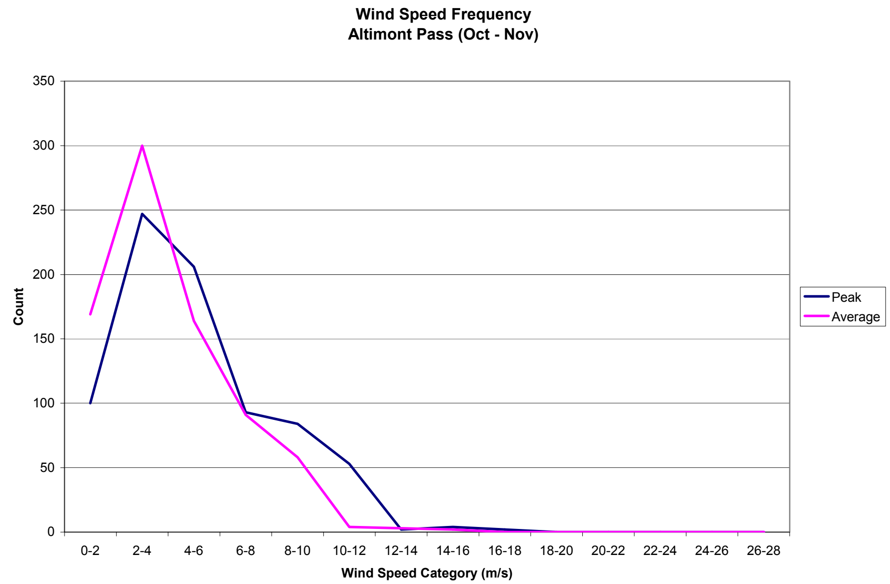
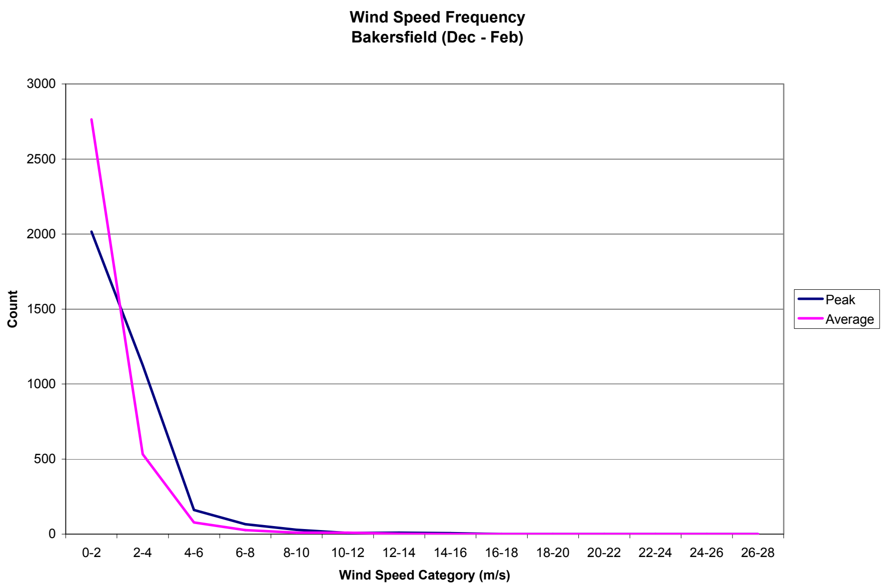
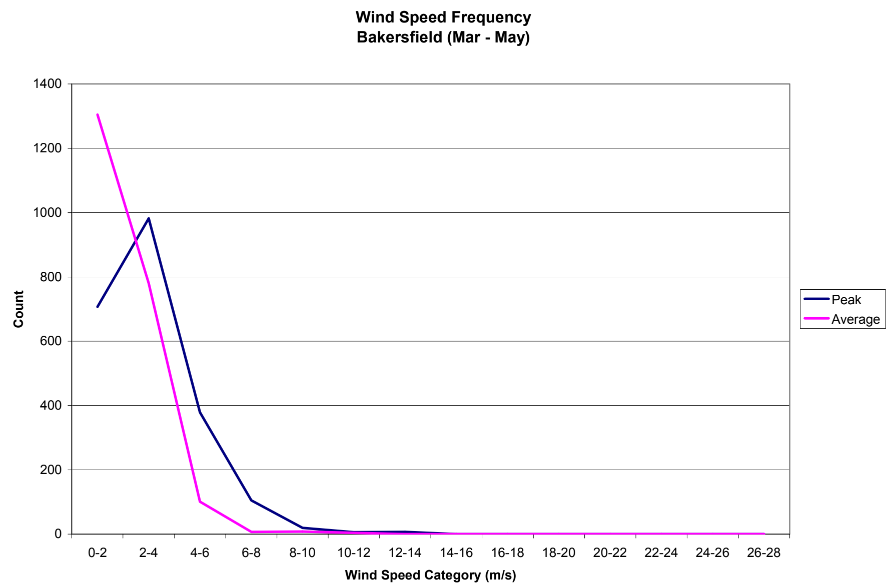
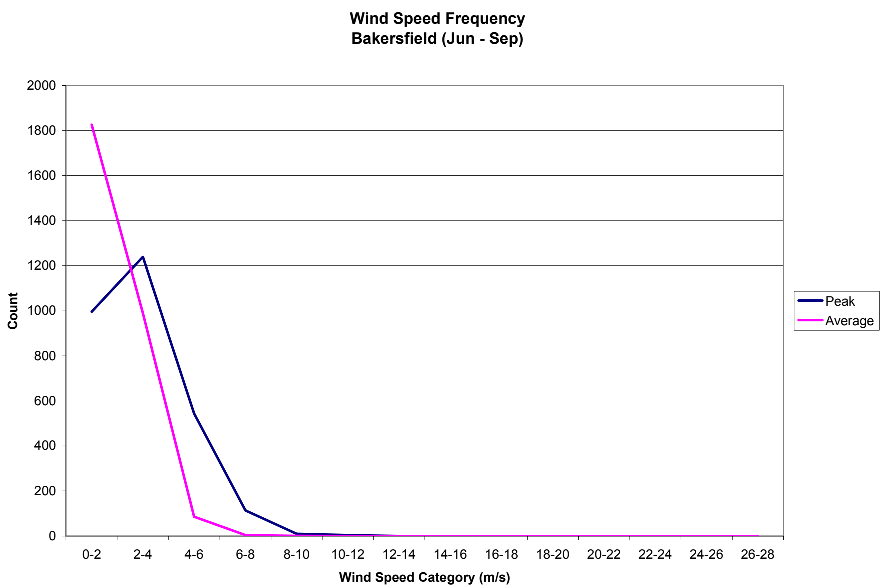


Figure 4. Altimont Pass Wind Speed Distributions







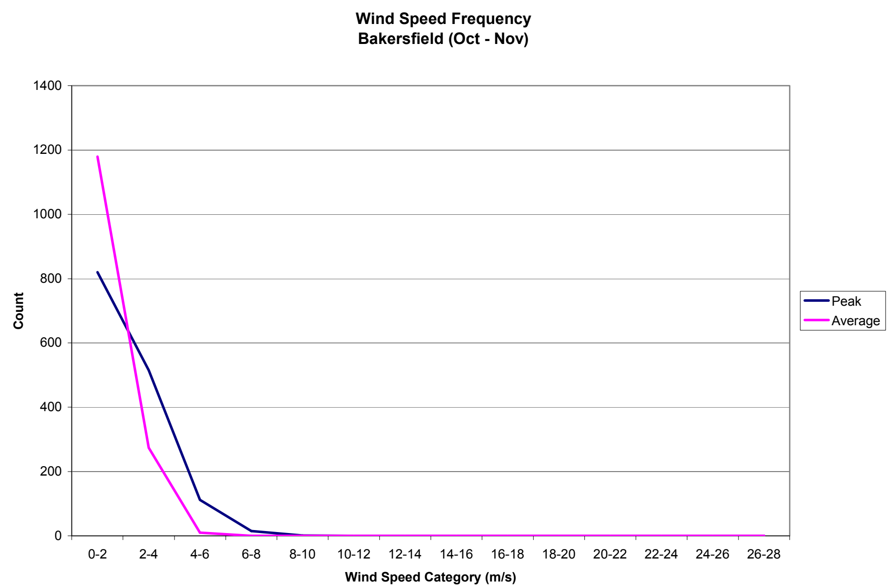


Figure 5. Bakersfield Wind Speed Distributions

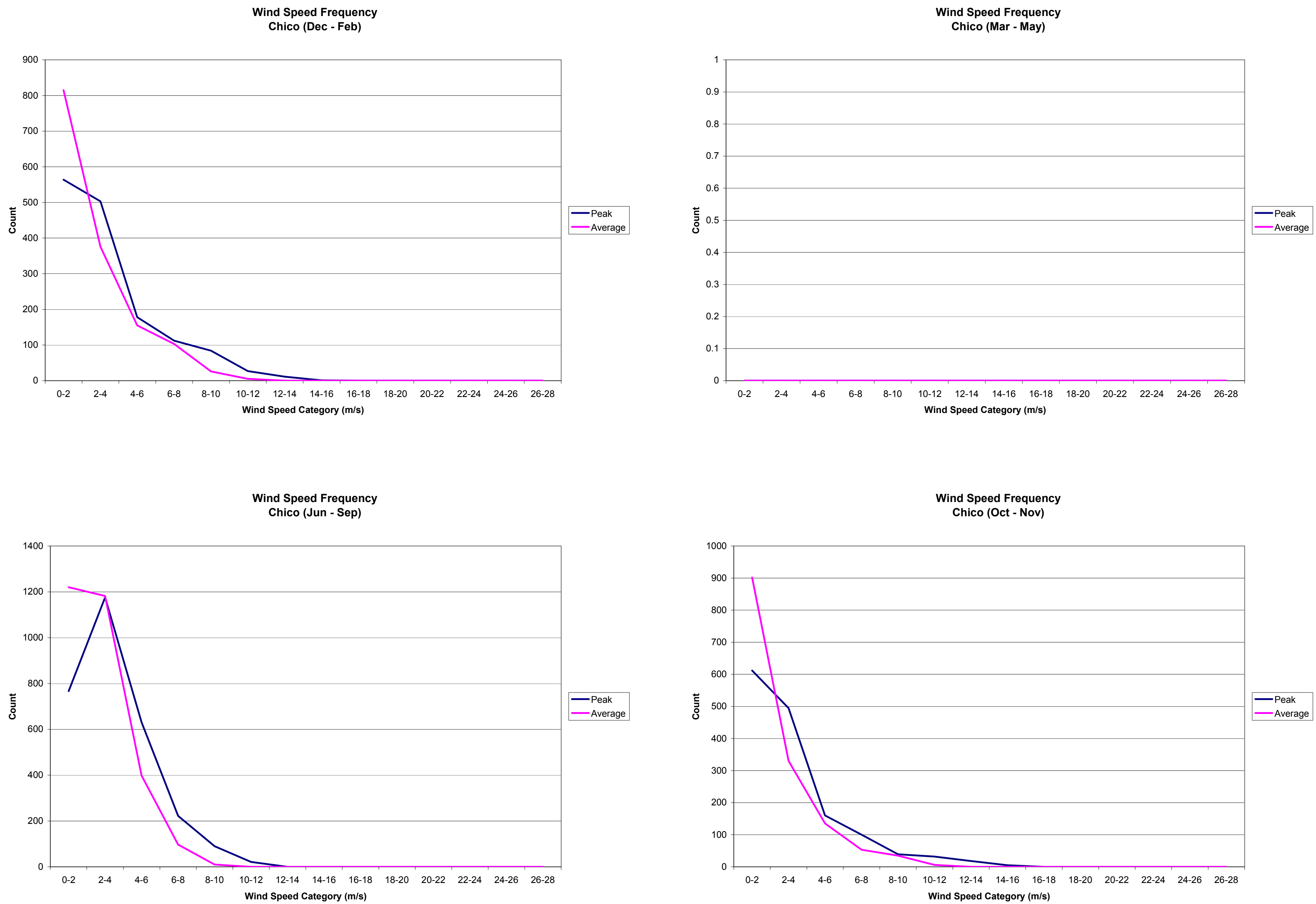


Figure 6. Chico Wind Speed Distributions.

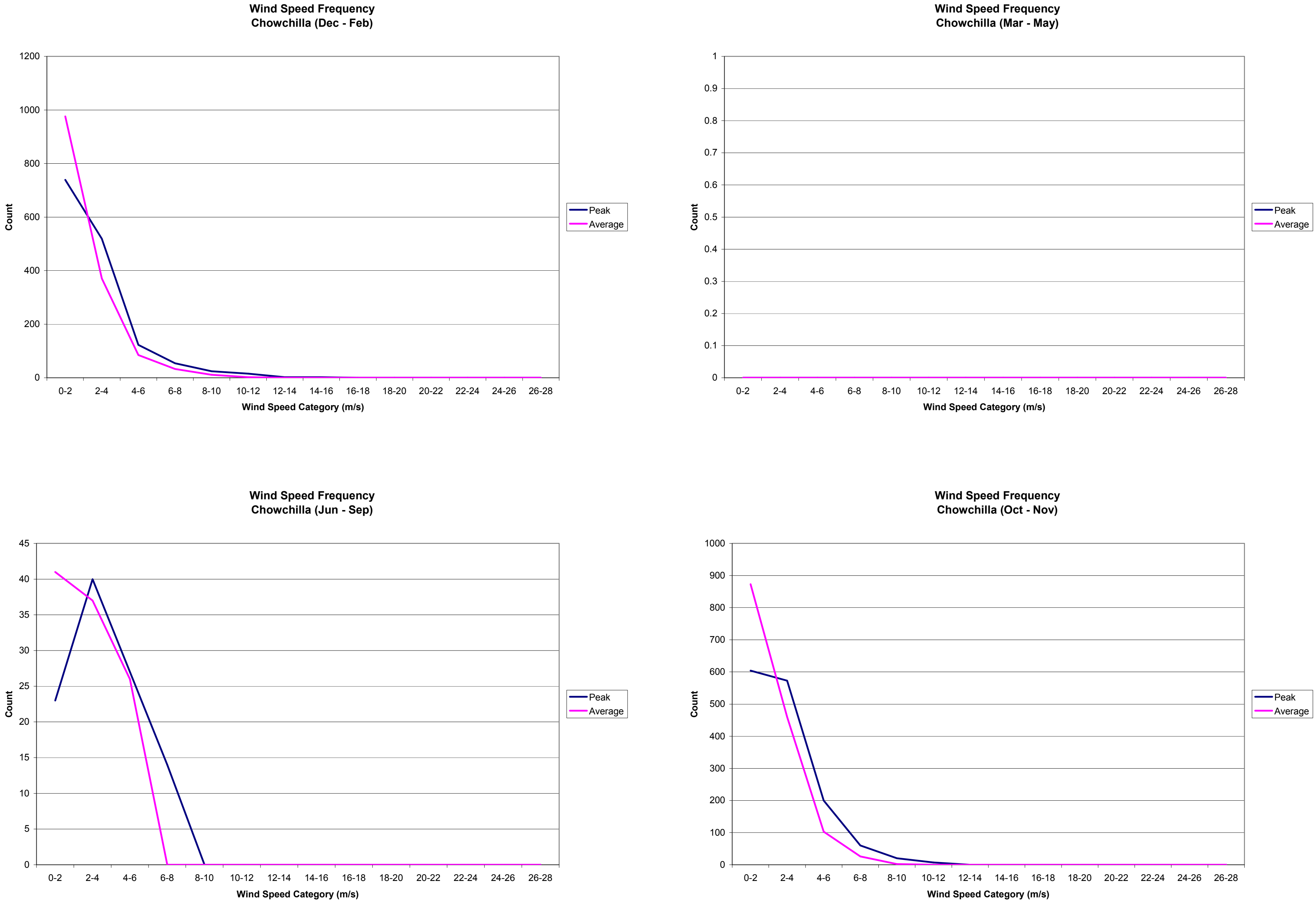


Figure 7. Chowchilla Wind Speed Distributions.

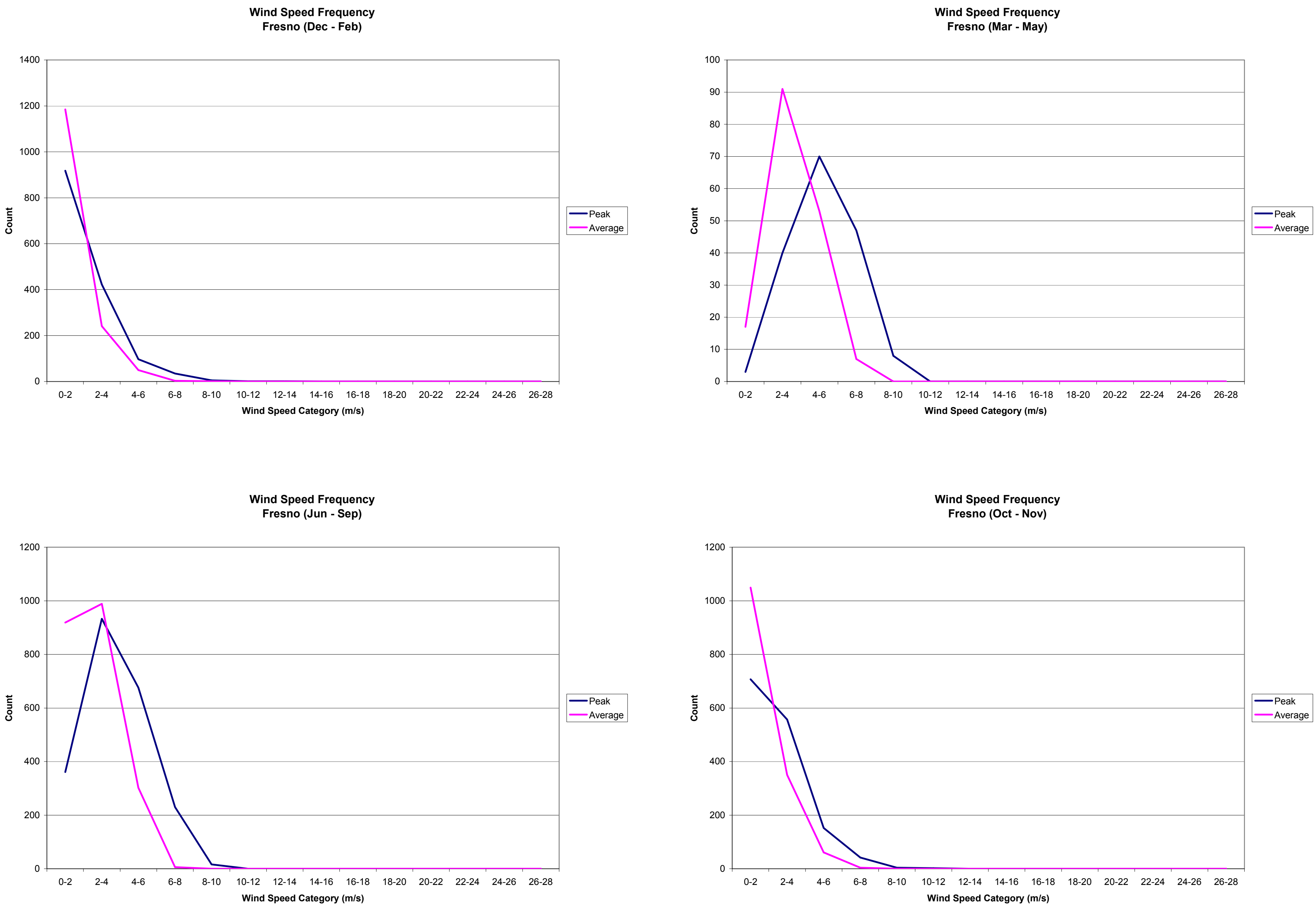


Figure 8. Fresno Wind Speed Distributions.

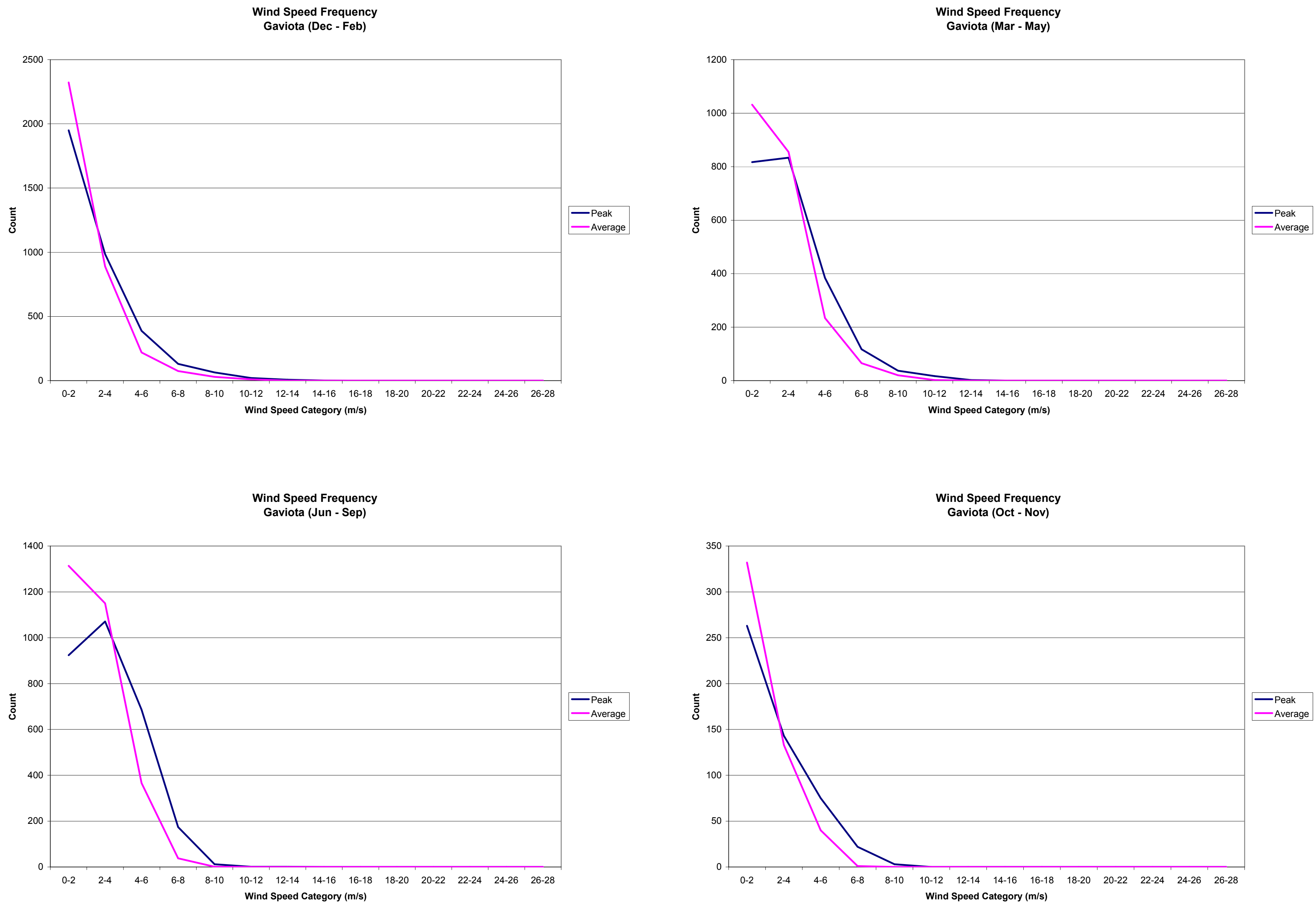


Figure 9. Goleta Wind Speed Distributions.

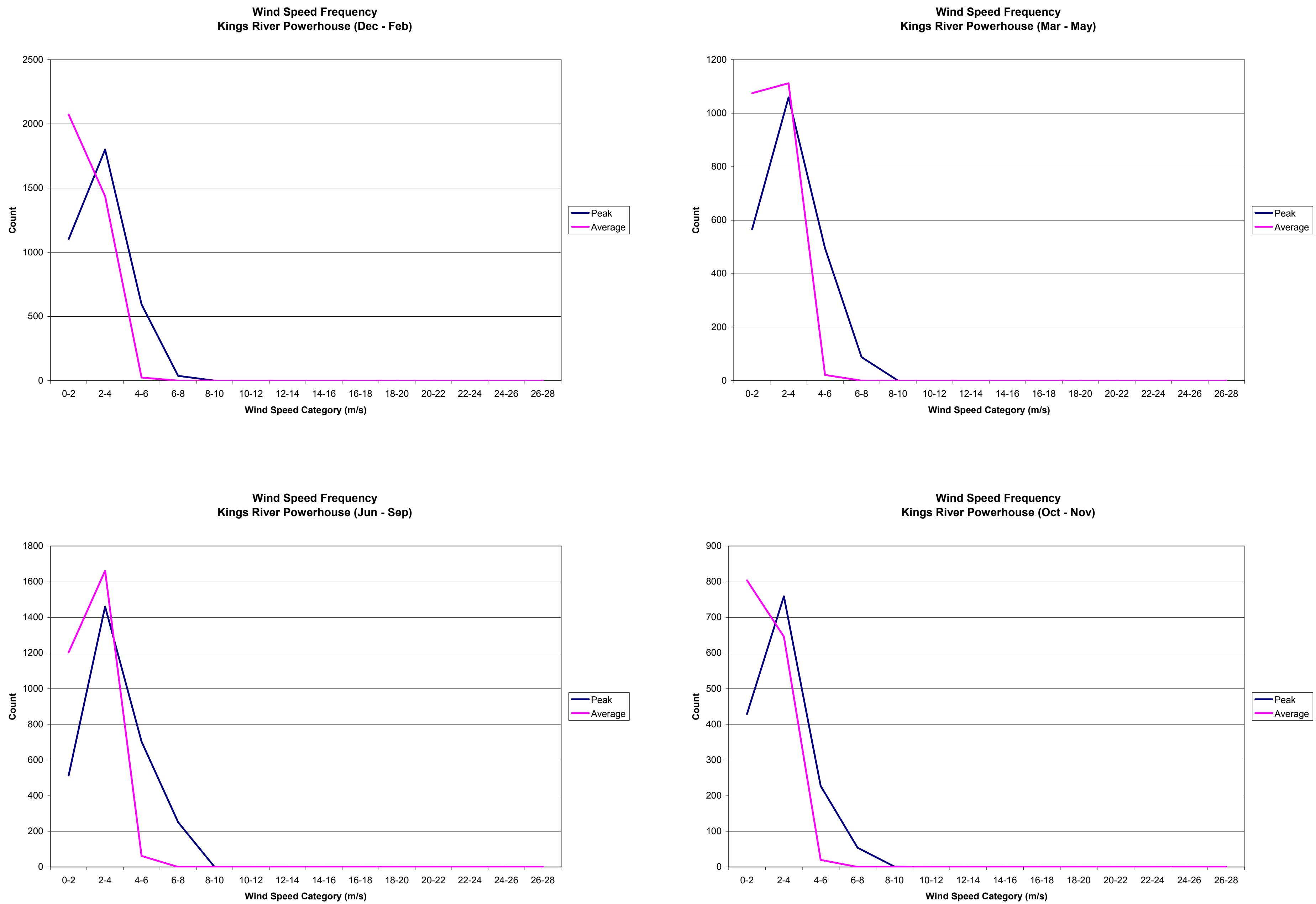


Figure 10. Kings River Powerhouse Wind Speed Distributions.

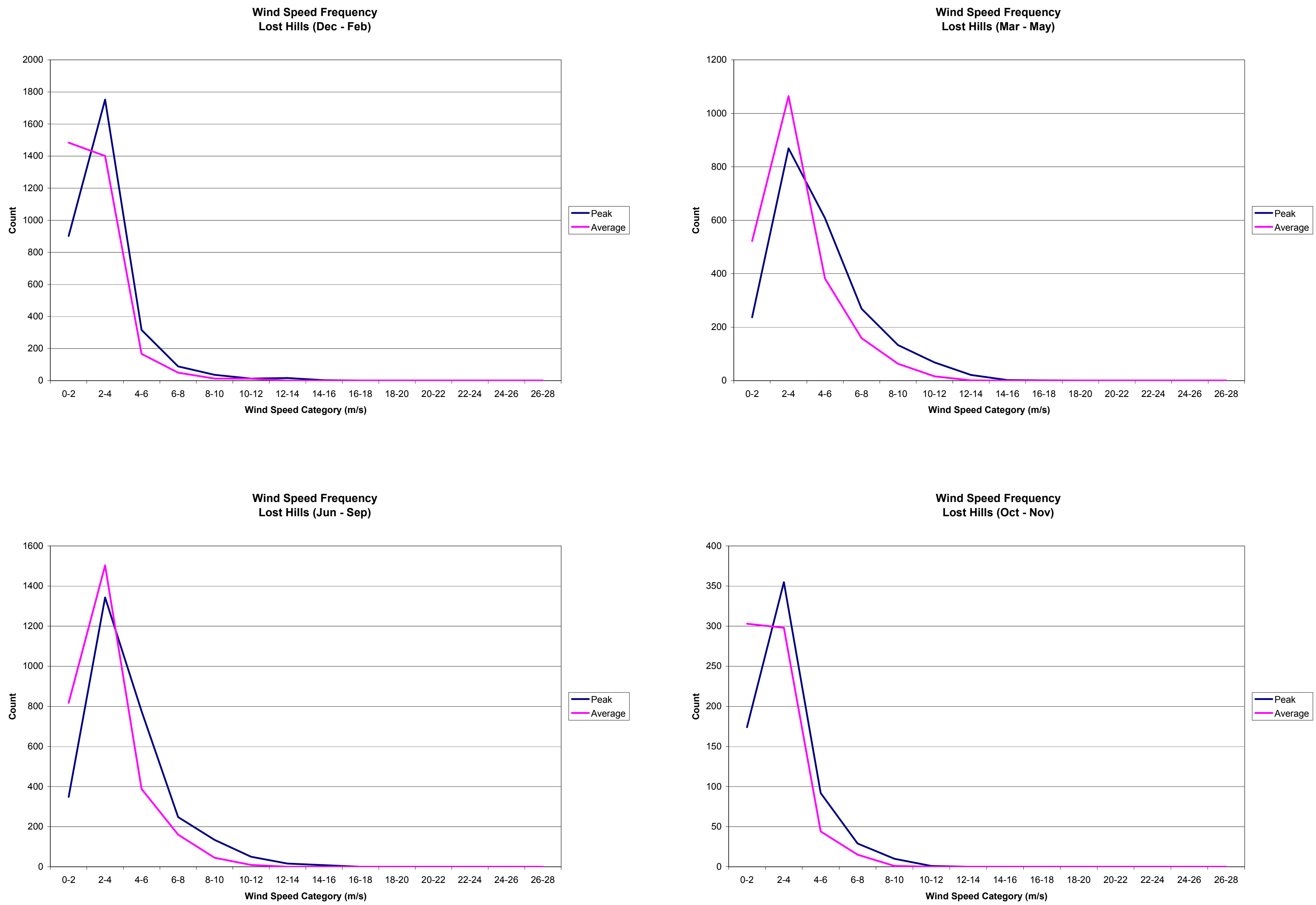


Figure 11. Lost Hills Wind Speed Distributions

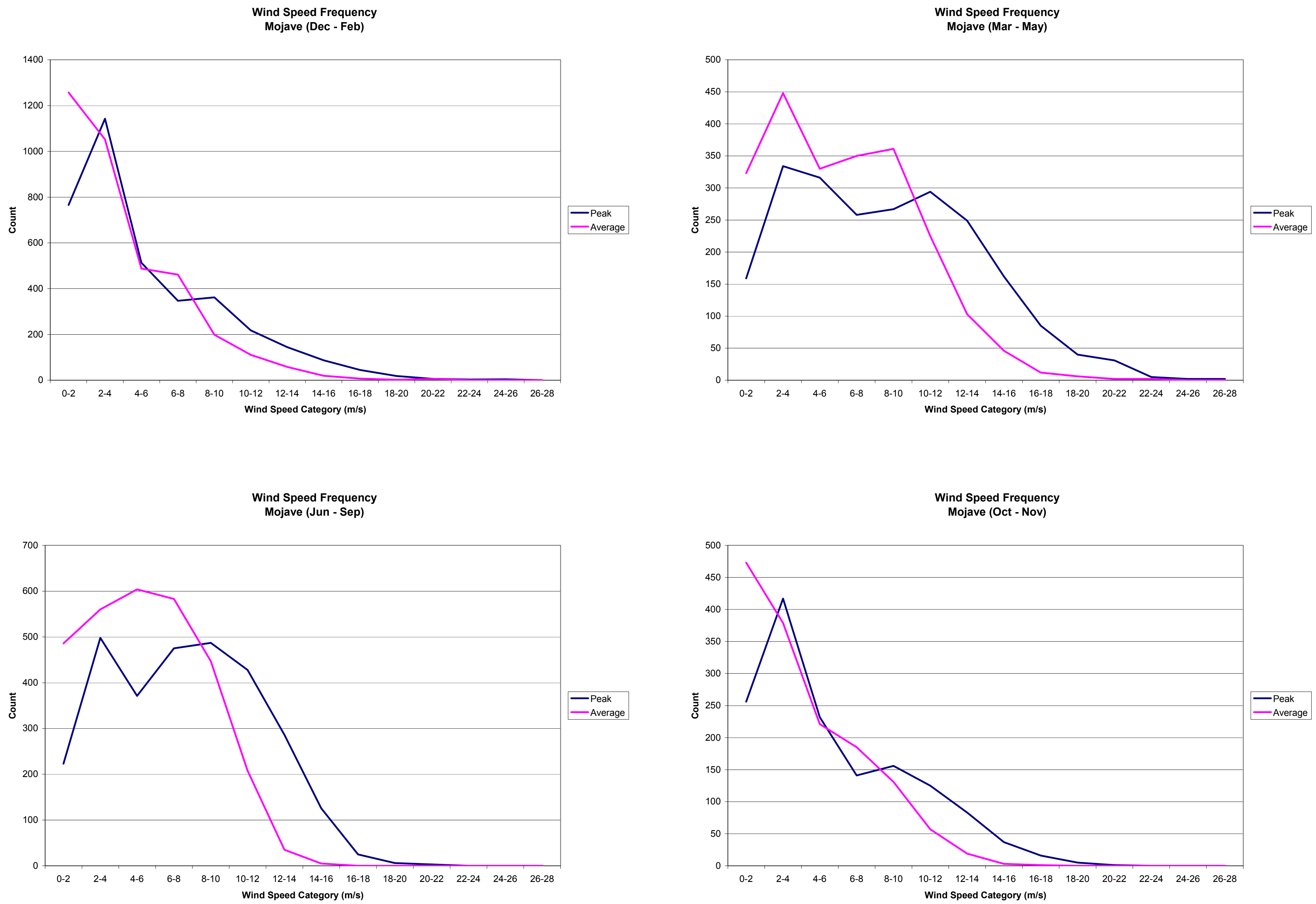
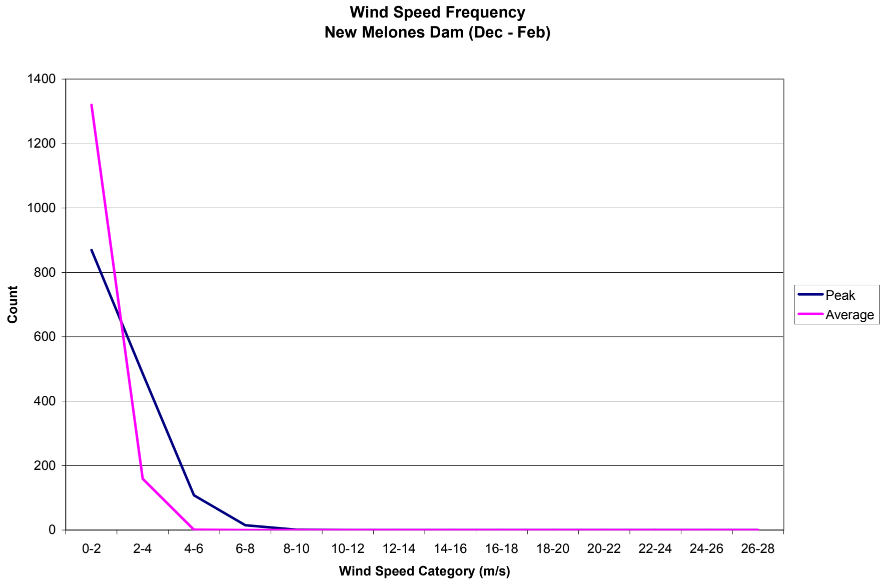
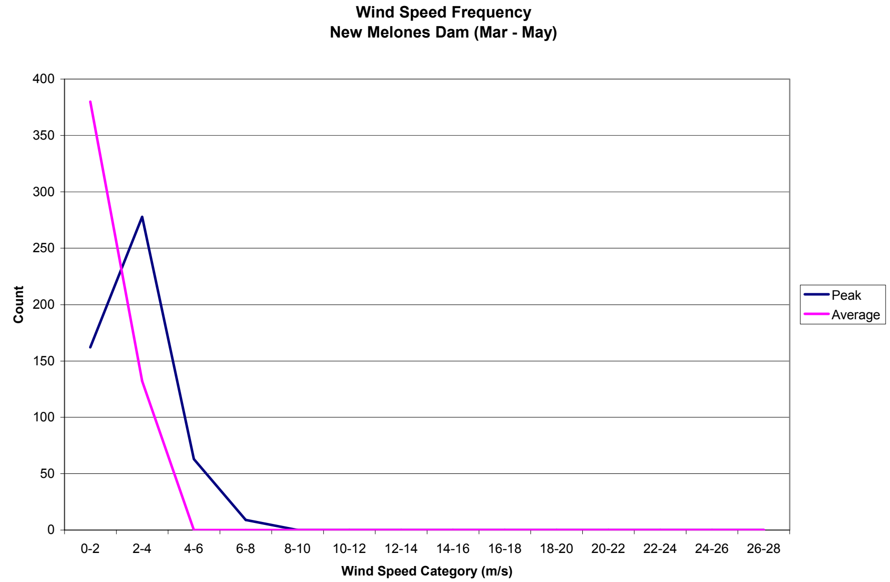
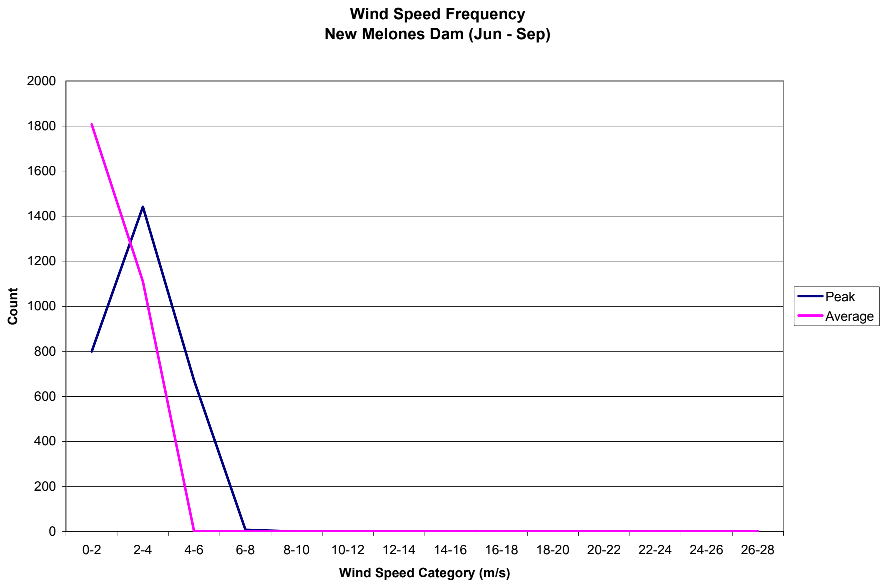


Figure 12. Mojave Wind Speed Distributions







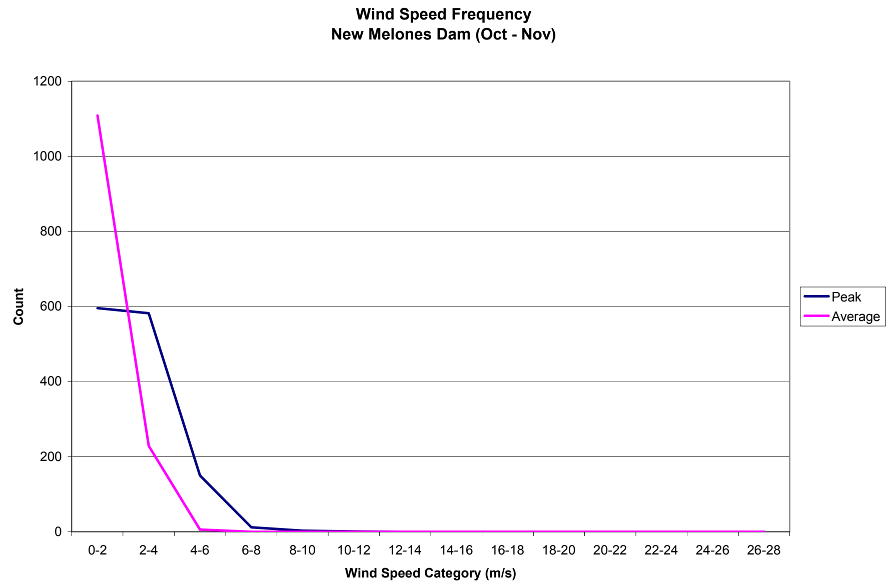


Figure 13. New Melones Dam Wind Speed Distributions

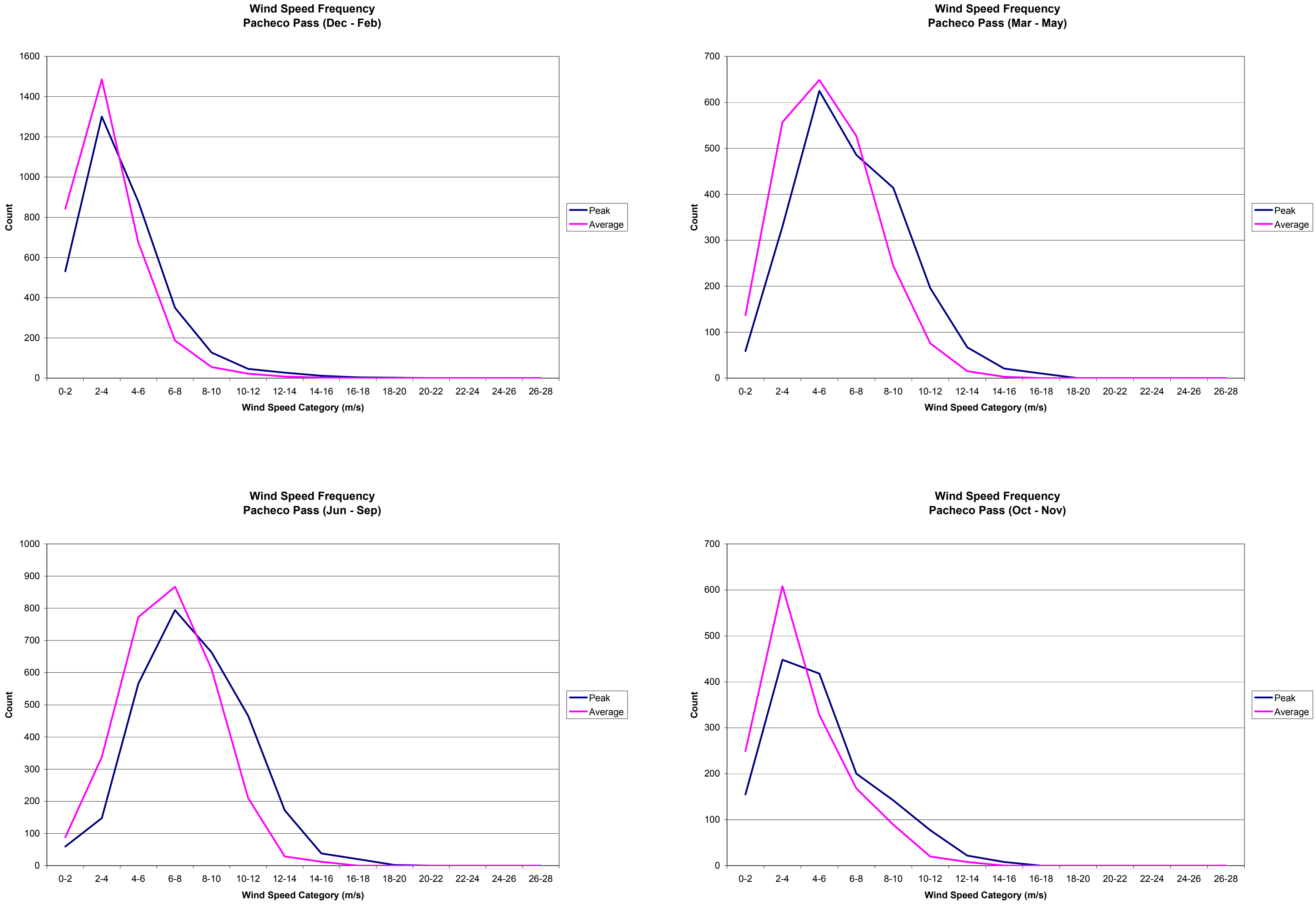
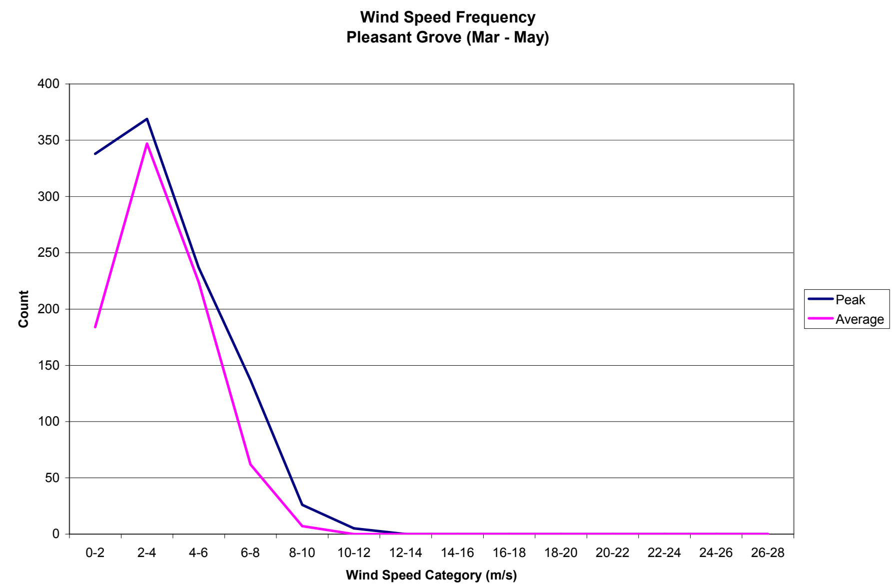
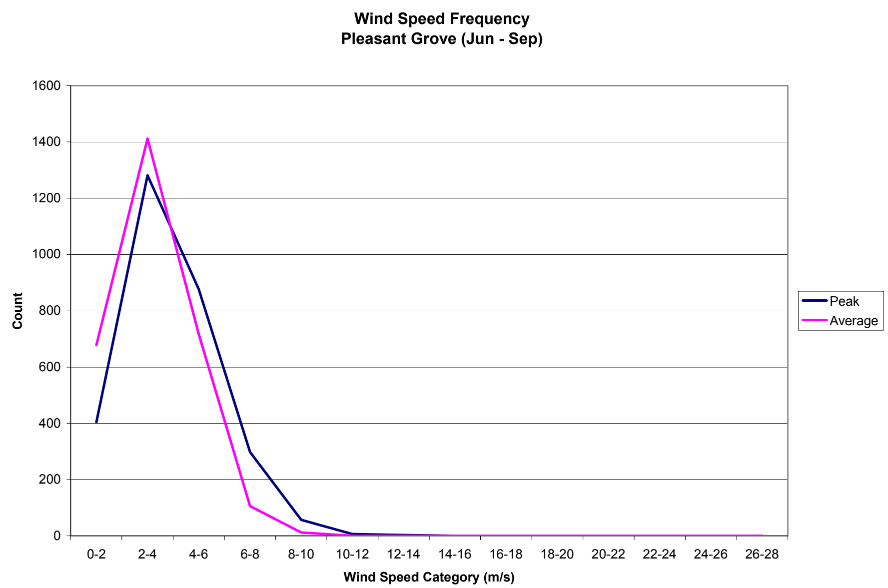


Figure 14. Pacheco Pass Wind Speed Distributions

no data available





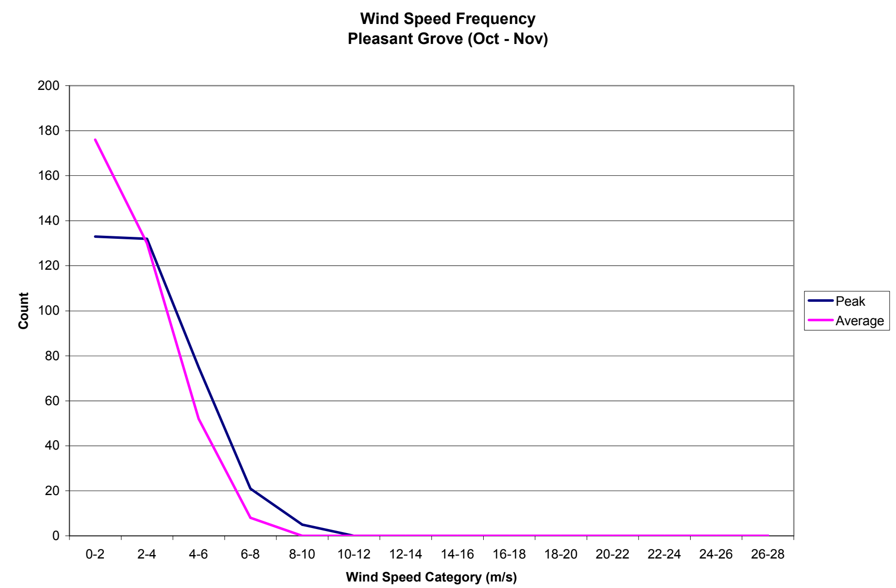


Figure 15. Pleasant Grove Wind Speed Distributions

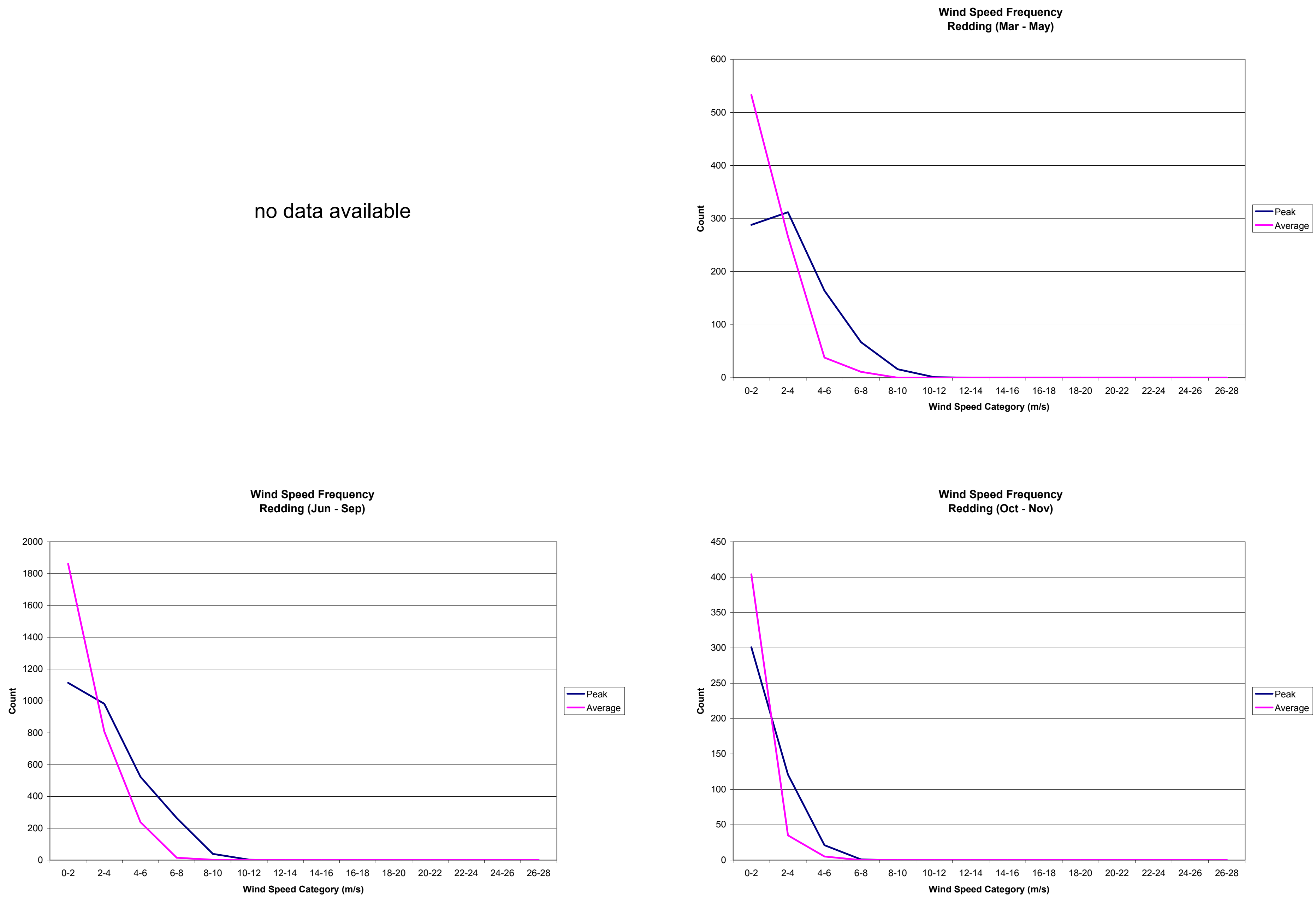
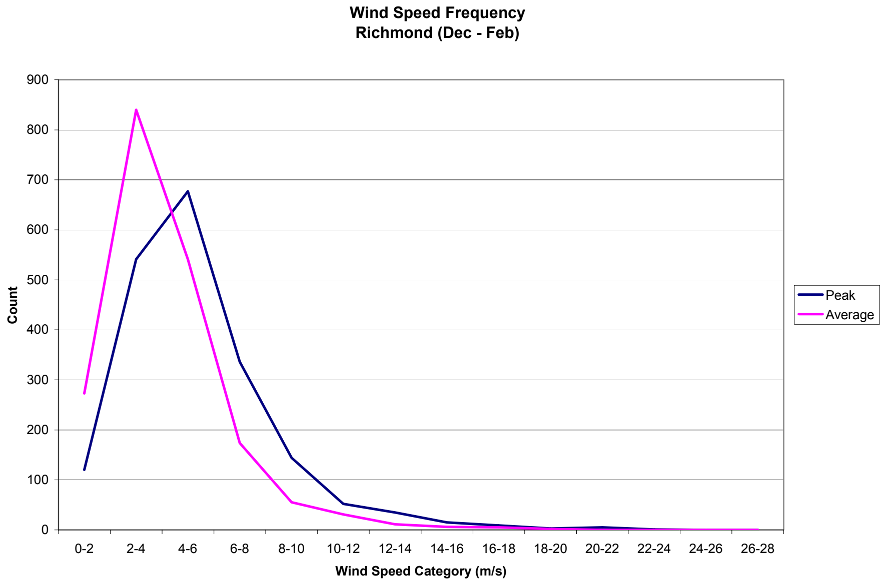
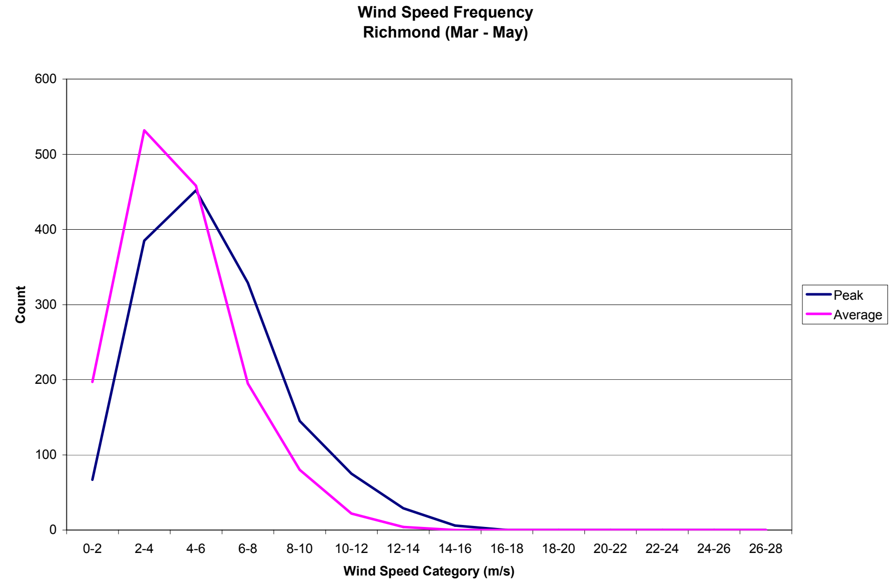
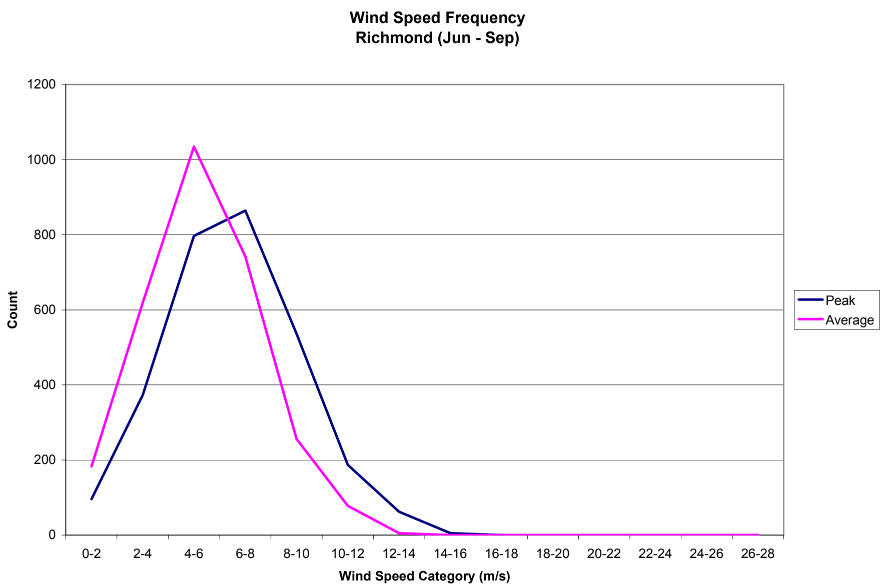


Figure 16. Redding Wind Speed Distributions







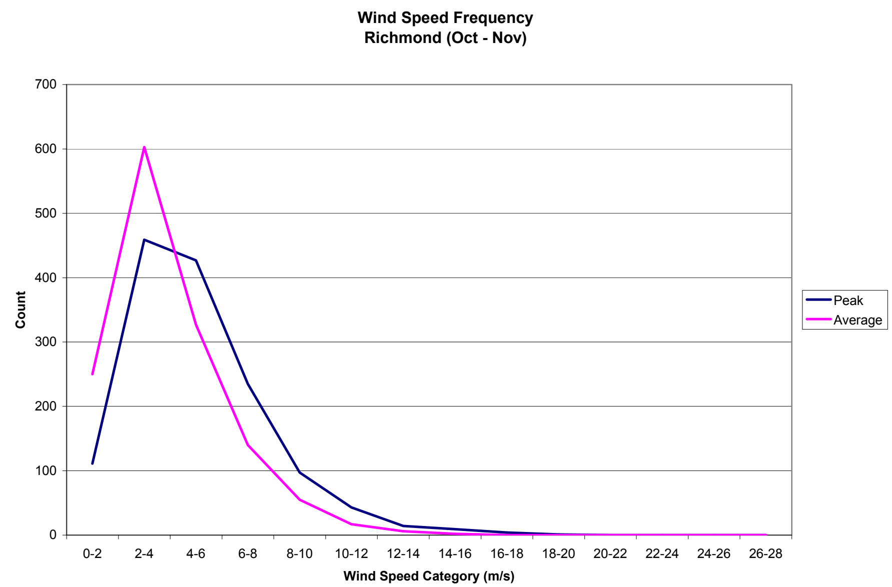
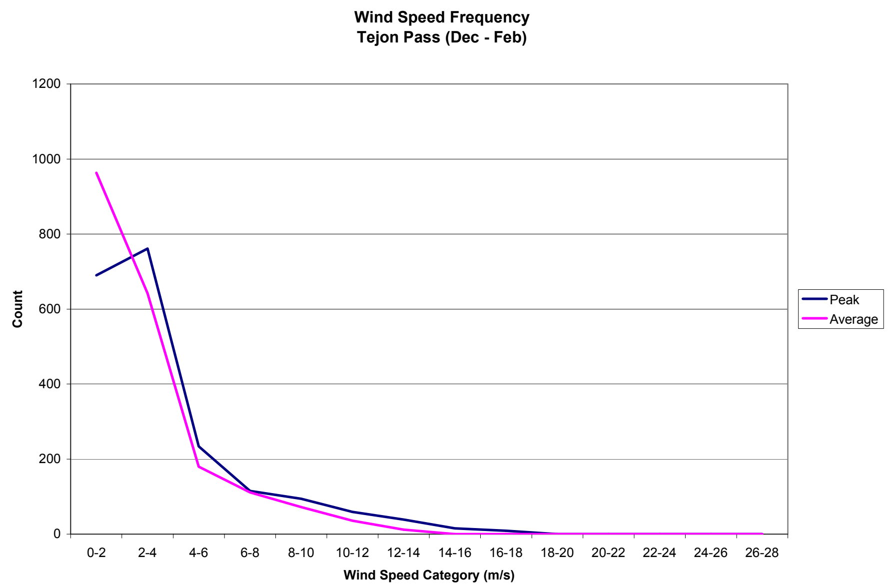
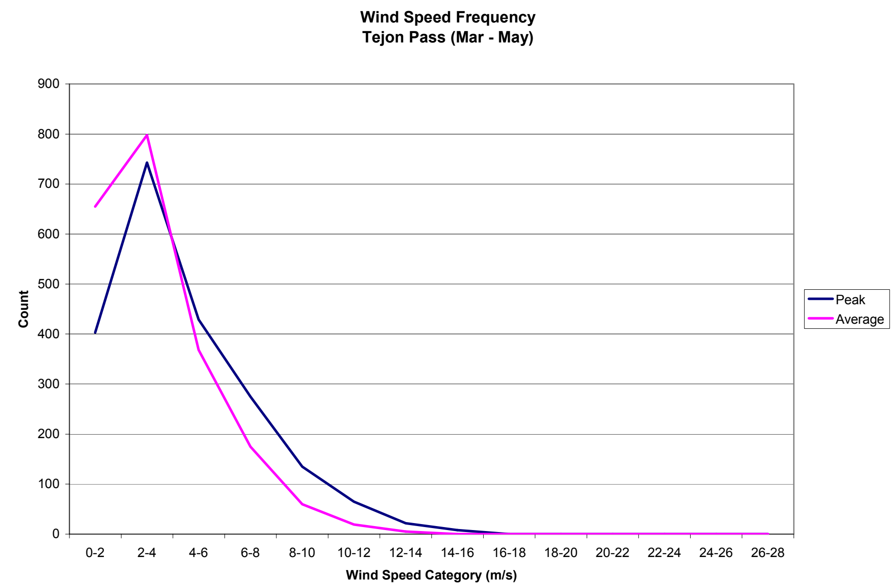
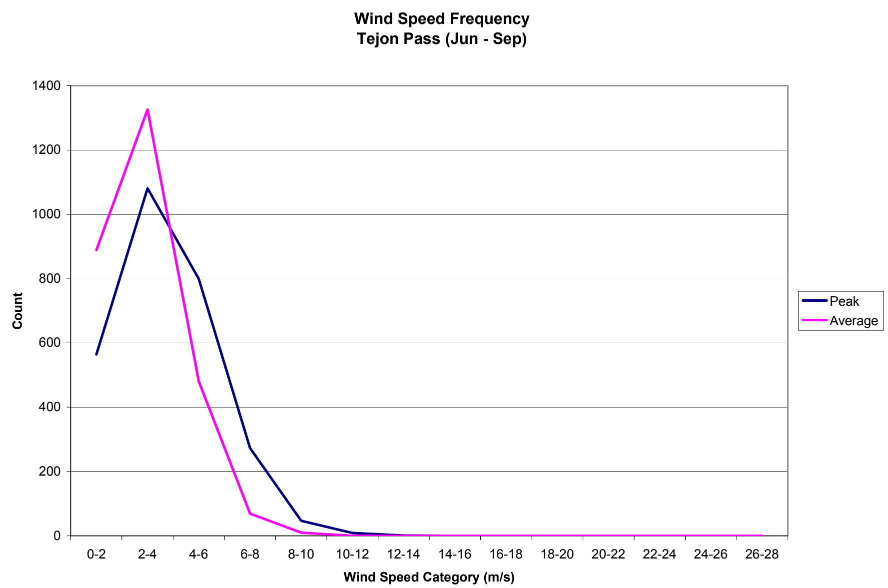


Figure 17. Richmond Wind Speed Distributions







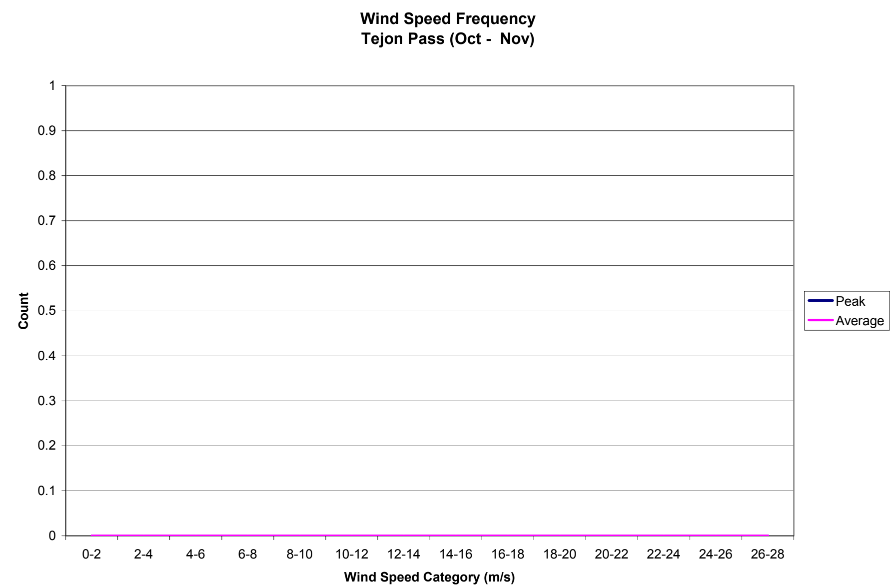


Figure 18. Tejon Pass Wind Speed Distributions

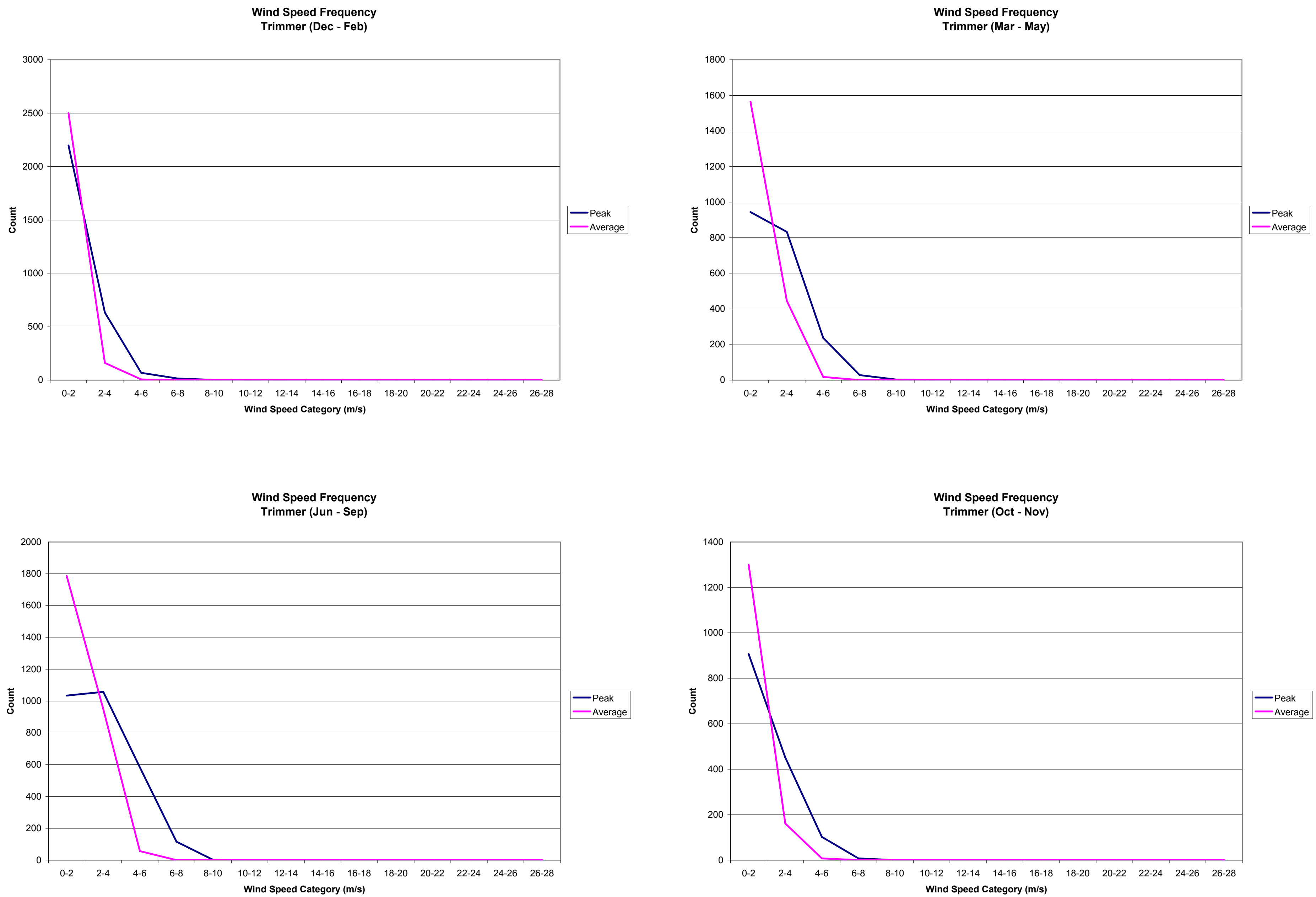


Figure 19. Trimmer Wind Speed Distributions

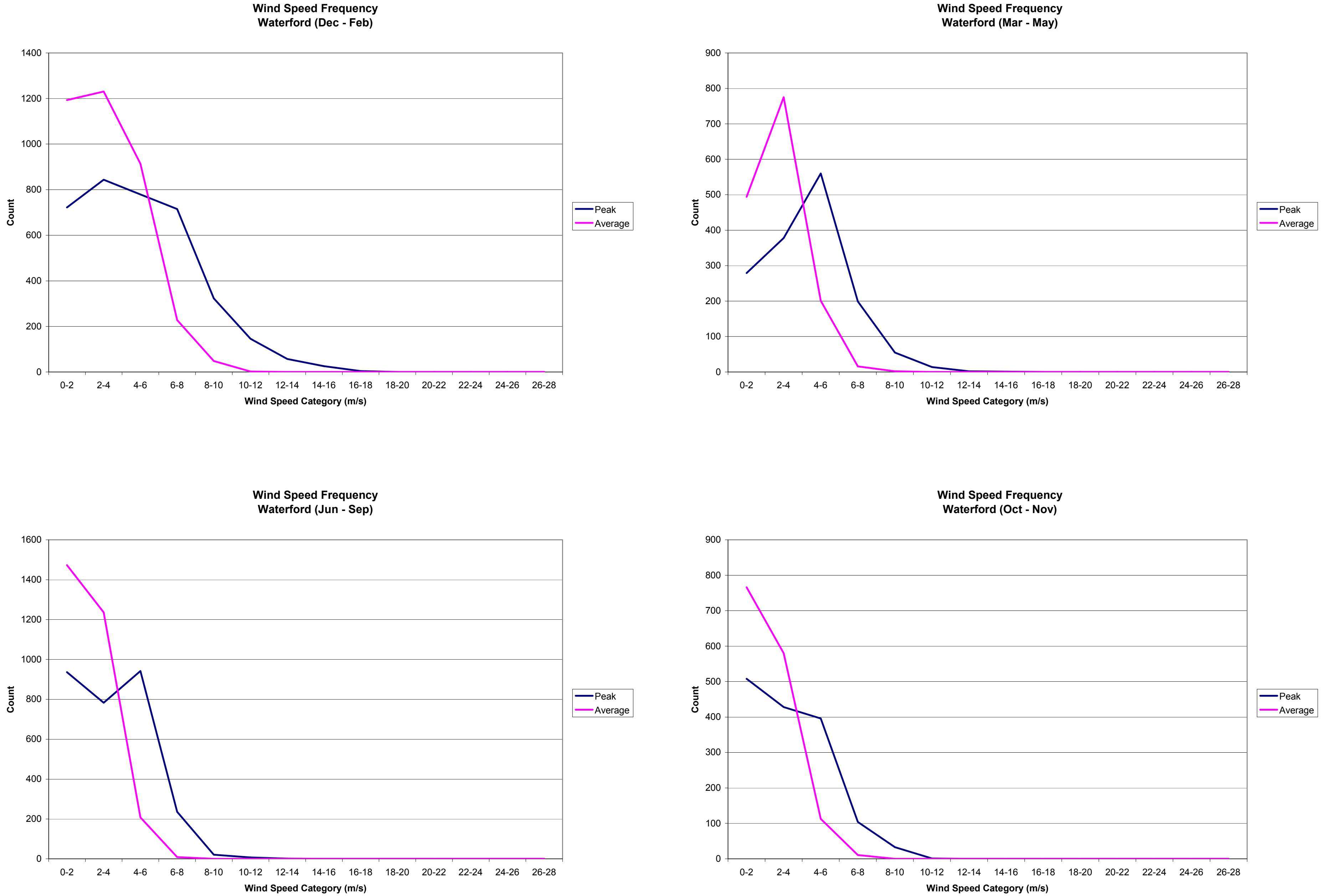


Figure 20. Waterford Wind Speed Distributions